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# Soberanes Fire

# Watershed Emergency Response

# Team Report

## CA-BEU-003422

## September 29, 2016

# Table of Contents

*Appendices*



# List of Figures



# List of Tables

# List of Abbreviations

| | |
|---|---|
| BAER | Burned Area Emergency Response |
| BARC | Burned Area Reflectance Classification |
| BOF | California State Board of Forestry and Fire Protection |
| CAL FIRE | California Department of Forestry and Fire Protection |
| CalVeg | Classification and Assessment with Landsat of Visible Ecological Groupings |
| Caltrans | California Department of Transportation |
| CEG | Certified Engineering Geologist |
| CFS | Cubic Feet per Second |
| CGS | California Geological Survey |
| CVRWQCB | Central Valley Regional Water Quality Control Board |
| DWR | California Department of Water Resources |
| EHR | Erosion Hazard Rating |
| EWP | Emergency Watershed Protection Program |
| FEMA | Federal Emergency Management Agency |
| FRAP | Fire and Resource Assessment Program |
| FT | Flow Transference Method |
| GIS | Geographic Information System |
| GPS | Global Positioning Satellite |
| HEC-HMS | Hydraulic Engineering Center-Hydraulic Modeling System |
| HUC | Hydrologic Unit Code |
| LiDAR | Light Detection and Ranging |
| MPWMD | Monterey Peninsula Water Management District |
| NOAA | National Oceanographic and Atmospheric Administration |
| NRCS | Natural Resources Conservation Service |
| NWS | National Weather Service |
| PE | Professional Engineer |
| PG | Professional Geologist |
| PH | Professional Hydrologist (AIH) |

| | |
|---|---|
| RSAC | Remote Sensing Application Center |
| RI | Return Interval |
| RPF | Registered Professional Forester |
| USDA | United States Department of Agriculture |
| USFS | United States Forest Service |
| USGS | United States Geological Survey |
| VARs | Values at Risk |
| WERT | Watershed Emergency Response Team |

# 1.0 Introduction

The following report presents the results of a rapid assessment of post-fire geologic and hydrologic hazards to life and safety (i.e., collectively known as “Values at Risk”) for non-federal lands affected by the 2016 Soberanes Fire in Monterey County, California. Wildfire can have profound effects on watershed processes. Wildfire-induced loss of surface cover and enhancement of soil water repellency from wildfire can enhance runoff generation and the erosive power of overland flow, resulting in accelerated erosion of material from hillslopes. Increased runoff can also erode significant volumes of material stored within channels. A primary concern for burned watersheds is the increased potential for damaging flood flows and increased probability for debris flow occurrence.

Debris flows are among the most hazardous consequences of rainfall on burned hillslopes. Debris flows pose a hazard distinct from other sediment-laden flows because of their unique destructive power. Debris flows can occur with little warning and can exert great impulsive loads on objects in their paths. Even small debris flows can strip vegetation, block drainage ways, damage structures, and endanger human life. Additionally, sediment delivery from debris flows can “bulk” the volume of flood flows, creating an even greater downstream flooding hazard. As winter approaches, it is critical that people who live in and downstream from large fires implement emergency protection measures where appropriate, remain steadfast and alert of weather conditions, and be ready to evacuate if necessary during large winter storms.

When wildfire-induced threats to life and safety are present, a state team of civil engineers, engineering geologists and California Department of Forestry and Fire Protection (CAL FIRE) staff can be assembled into a Watershed Emergency Response Team (WERT) to assess potential hazards from post-fire debris flows, hyperconcentrated flows, and flood flows. CAL FIRE senior staff, along with the California Office of Emergency Services (CalOES), determined that a WERT was needed for the Soberanes Fire.

## 1.1 Background

Due to the large area of private land affected by the fire (Figure 1) and the risk to life-safety, a multi-agency WERT comprised of individuals with expertise in engineering geology, geomorphology, hydrology, forestry, GIS, and civil engineering was assembled for the Soberanes Fire (Table 1). WERT members were selected that either (1) have considerable post-fire assessment experience, or (2) are trainees. Following the selection of team members, the WERT compiled mapping products during the week of August 29th and met as a team to discuss deployment, which was scheduled for September 6, 2016. The WERT field eam was supported in the home offices by a select number of technical specialists including foresters, engineering geologists, GIS analysts, and a hydrologist.

On August 29, 2016, a United States Forest Service (USFS) Burned Area Emergency Response (BAER) team was deployed to the Soberanes Fire area. BAER teams perform similar work to the WERT (http://www.nifc.gov/BAER/Page/NIFC_BAER.html), with a primary focus on assessing hazards on federal lands (Figure 1). However, BAER teams regularly do a preliminary reconnaissance of Values at Risk (VARs) on private lands, and will typically


**Figure 1. Overview Map**
Soberanes Incident
CA-BEU-003422

generate soil burn severity maps that include portions of the burned area outside of federal lands. It was clearly recognized that in order to avoid duplication of efforts and make the most of mutual opportunities, it was critical for the WERT to coordinate with and compliment the efforts of the BAER team.

The complete WERT arrived at the Soberanes Incident area on September 6, 2016 and interfaced with the BAER team over the next two days (9/6 through 9/8) to ensure a complete transfer of information. The BAER team concluded their evaluation and departed the Soberanes Incident area on September 8, 2016. The BAER team report is available at the following link: http://www.co.monterey.ca.us/oes/Soberanes-Post-Fire-and-Recovery-Information.asp.

## 1.2 WERT Objectives

Primary objectives for a Phase I WERT effort are to conduct a rapid preliminary assessment to:

- Identify types and locations of on-site and downstream threats to public health or safety from landsliding, debris flows, flooding, road hazards, and other fire related problems.
- Develop preliminary emergency protective measures needed to avoid life-safety threats.

The Phase I WERT objectives are achieved through an explicit process which combines analysis, modeling, and professional judgement to assess risk to life, safety, and property (CAL FIRE, 2016). The process also emphasizes communication and outreach to inform responsible authorities and parties about post-fire watershed hazards (Figure 2).

The BAER team noted VARs on private land, but did not provide an in-depth assessment of potential hazard to these sites. The WERT assessment differs from the BAER team assessment in that it explicitly focuses on site-specific VARs located on private land that were affected by the Soberanes Fire (Figure 1). The WERT assessment also provides a much more focused look at VARs for non-federal lands. It should be noted however, that the assessment was conducted in an expedited manner to maximize the time for responsible parties to implement emergency mitigation activities prior to the onset of winter rains, and as such the WERT assessment should not be considered a detailed and comprehensive analysis of potential hazards.

**Table 1.** Phase I WERT team members.

| Main Team | | | |
|---|---|---|---|
| **Name** | **Position** | **Agency** | **Expertise-Position** |
| Drew Coe, RPF #2981 | Team Leader | CAL FIRE | Forestry/Hydrology |
| Dave Longstreth, CEG #2068 | Co-Leader | CGS | Engineering Geology |
| Patrick Brand, CEG #2542 | Team Member | CGS | Engineering Geology |
| Jonathan Woessner, RPF #2571 | Team Member | CAL FIRE | Forestry |
| Jonathan Pangburn, RPF #2862 | Team Member | CAL FIRE | Forestry |
| Trevor Morgan, PE #79967 | Team Member | DWR | Civil Engineer/Hydrology |
| Stacy Stanish, RPF #3000 | Team Member | CAL FIRE | GIS/Forestry/Biology |
| Christopher Gryszan, CEG #2640 | Team Member | CGS | Engineering Geology |
| René Leclerc, PE #82180 | Team Member | CVRWQCB | Civil Engineer/ Geomorphology |
| German Whitley | Team Member | Deer Creek Resources | GIS/Hydrology |
| **Adjunct Team** | | | |
| Jeremy Lancaster, CEG #2379 | Team Member | CGS | Engineering Geology |
| Kelly Larvie | Team Member | CAL FIRE-FRAP | Research Analyst, GIS |
| Pete Roffers, PG #9100 | Team Member | CGS | Engineering Geology, GIS |
| Solomon McCrea, CFM #3527 | Team Member | CGS | Research Analyst, GIS |
| Pete Cafferata, PH #1676, RPF #2184 | Team Member | CAL FIRE | Forestry/Hydrology |

## 2.0 Methods

The BAER team provided the initial coarse scale assessment of the burned area (USFS, 2016). The WERT relied upon data and analysis performed by the USFS BAER team, and supplemented analysis based on specific values at risk and field observations. The following section briefly explains the office, modeling, and field methodologies used for assessing hazards to values at risk.

### 2.1 Pre-Field, Office Methods

In order to compare field observations with map and modeled data, ArcGIS[1] data were uploaded to the "Collector"[2] application on two iPads and multiple smart phones. Data from the Soberanes Fire Soil Burn Severity map (see Section 2.1.1) were added onto a topographic

[1] https://www.arcgis.com/features/index.html
[2] http://doc.arcgis.com/en/collector/

base layer using ArcGIS. Additional GIS layers added to the base layer included, but were not limited to:

- BARC field verification points and polygons
- VAR points and polygons from the BAER team
- Fire perimeter
- Fire control lines
- Fire history
- Basin-Indians Complex VAR points generated during the 2008 post fire assessment.
- United States Geological Survey (USGS) debris flow model segments and basin probabilities for 40 mm $hr^{-1}$ storm
- BAER team "Pour Points"
- Watershed boundaries (HUC-12)
- Federal Emergency Management Agency (FEMA) Special Flood Hazard Areas
- Department of Water Resources (DWR) Special Awareness Floodplains
- Hydrography
- Building clusters
- State Responsibility Area (SRA)
- Ownership
- Roads
- Geology
- Slope gradient
- Topographic hillshade
- LiDAR imagery

The Collector application was the primary platform for collecting data to characterize the VARs, the nature of the hazard, and the potential emergency measures to mitigate the hazard. The information was georeferenced to a point or polygon for incorporation into ArcGIS. The Collector application was also capable of taking georeferenced photographs. All information entered into the Collector application was also recorded manually on datasheets.

Additionally, georeferenced Portable Document Format (pdf) maps were produced for team members to use as a back up to the "Collector" application. Maps including the most critical layers were converted to georeferenced pdf files. The pdf files were uploaded to WERT member's smart phones and iPads to use for supplementary and back-up data collection. Team members used the Avenza "PDF Maps"[3] application to track their locations in the field relative to mapped GIS features, and to take supplementary notes and photographs.

### 2.1.1 Soil Burn Severity Maps

The degree to which fire affects soil properties, along with other controlling factors, is important for predicting the potential for increased runoff and sedimentation (Keeley, 2009). Soil burn severity mapping reflects the spatial distribution of the fire's effects on the ground surface and soil conditions, and is needed in order to rapidly assess fire effects, identify potential values at

[3] http://www.avenza.com/pdf-maps

risk, and prioritize field assessment (Parsons et al., 2010). Soil burn severity is determined from Landsat satellite imagery-derived Burned Area Reflectance Classification (BARC) maps (http://www.fs.fed.us/eng/rsac/baer/barc.html). The BARC map is field verified using standardized methods to create a soil burn severity map (Parsons et al., 2010). The soil burn severity map for the Soberanes Fire was field verified and generated by the BAER team, and the WERT relied on the BAER team's soil burn severity map for their assessment. Appendix B shows the burn severity along with other information.

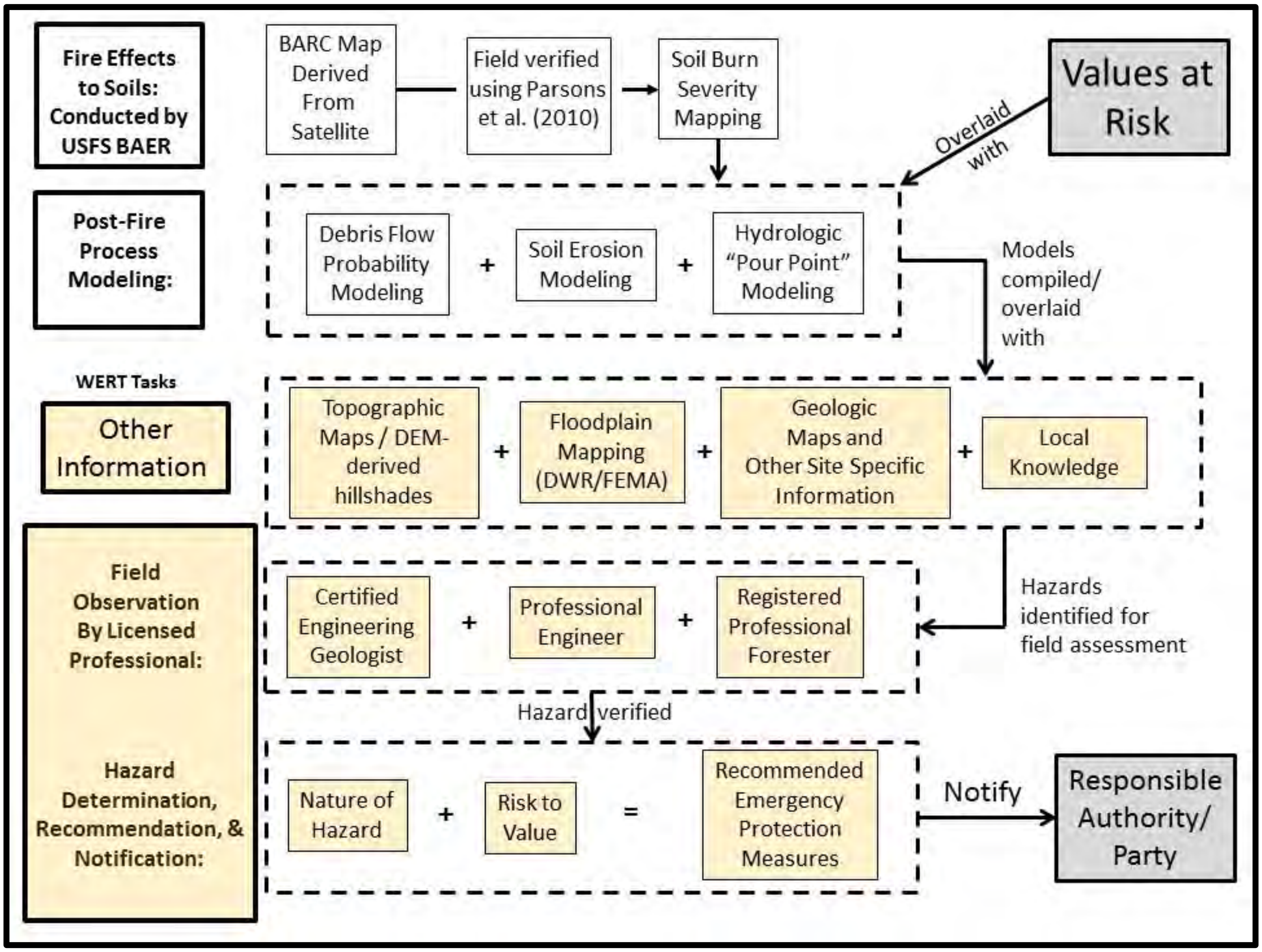


**Figure 2.** The process and methods for implementing a Phase I WERT for the Soberanes Fire.

### 2.1.2 Flood Hazard Maps

Flood hazard maps from the Federal Emergency Management Agency (FEMA) and the California State Department of Water Resources (DWR) were used in the WERT hazard assessment. FEMA flood hazard zone maps are available for areas subject to flooding from the burned area on the Carmel and Big Sur Rivers, Las Gazas Creek, and near the mouth of the Little Sur River. The DWR Awareness Floodplain Maps provide flood hazard mapping for communities not currently mapped by FEMA but where flood hazards are known to exist; other watersheds may also contain flood hazards but have not yet been assessed by FEMA or DWR. Awareness Floodplain Maps are available for parts of San Clemente and Pine Creeks draining to the Carmel River and for the lower Little Sur River. Both the FEMA and DWR maps show flood hazard zones that will be inundated by the flood event having a 1-percent chance of being equaled or exceeded in any given year (i.e., a 100-year flood event). It should be noted however that due to the effects of fire, these probabilities are likely elevated from those that the maps represent.

Flood history information was obtained from the FEMA Flood Insurance Study for Monterey County (FEMA 2009) and from United States Geological Survey (USGS) stream flow records at the following gages:

- Big Sur River Near Big Sur (Gage No. 11143000) - Unregulated[4]
- Carmel River at Robles Del Rio (Gage No. 11143200) – Low flow regulated by Los Padres Reservoir 11 mi upstream
- Carmel River Near Carmel (Gage No. 11143250) – Low flow regulated by Los Padres Reservoir

FEMA maps and Flood Insurance Study information were obtained from the FEMA Map Service Center web site at: http://msc.fema.gov/portal/advanceSearch.

DWR Floodplain Awareness Maps were obtained from DWR at: http://www.water.ca.gov/floodmgmt/lrafmo/fmb/fes/awareness_floodplain_maps/.

USGS stream flow records were obtained from the USGS at: http://waterdata.usgs.gov/ca/nwis/sw.

## 2.2 Modeling Methods

Various models were used to prioritize field reconnaissance and inform professional judgement. The models used in the assessment are summarized in the following sections.

### 2.2.1 USGS Post-fire Debris Flow Model

The USGS assessment uses results of the soil burn severity map along with empirical models to estimate the likelihood and potential volume of debris flows for selected basins in response to a design storm. The empirical models are based upon historical debris-flow occurrence and magnitude data, storm rainfall conditions, terrain and soils information, and burn-severity data from recently burned areas (Staley et al., 2016). Post-fire debris-flow likelihood, volume, and combined hazards are estimated at both the drainage-basin scale and in a spatially distributed manner along the drainage network within each basin. The characteristics of basins affected by

[4] A regulated river is one where downstream flows are altered by a major hydromodification (e.g. a large dam).

the fire were calculated using a geographic information system (GIS) with a minimum area of 0.2 $km^2$ and a maximum area of 8.0 $km^2$. Debris-flow likelihood and volume were estimated for each basin outlet as well as along the upstream drainage networks.

The US Geological Survey (USGS) preliminary hazard assessment of the Soberanes Fire can be accessed at:
http://landslides.usgs.gov/hazards/postfire_debrisflow/2016/20160722soberanes/

The USGS post-fire debris flow hazard model was employed for the Soberanes Fire to assist in the WERT's assessment of locations where hazards to life and property may exist. The debris flow likelihood maps based on the 28 mm $hr^{-1}$ (1.1 in $hr^{-1}$) design rainfall are presented in Appendix B, and illustrate the likelihood of debris flows occurring in response to a more frequent precipitation event. The WERT team used the USGS model results based on the 40 mm $hr^{-1}$ (1.6 in $hr^{-1}$) event to aid in our field assessment of values at risk. This less frequent and possibly extreme precipitation event emphasizes areas for field teams to focus their observations.

The debris flow likelihood maps categorize the results for each basin in percent likelihood with five groups:

- very low (0 to 20%)
- low (21 to 40%)
- moderate (41 to 60%)
- high (61 to 80%), and
- very high (81 to 100%)

By varying the precipitation input parameters, the basin probability analyses indicate that: when using the 20 mm $hr^{-1}$ (0.78 in $hr^{-1}$) precipitation event, 62 of 435 basins have likelihood of 50% or greater to produce debris flow[5]; when using the 24 mm $hr^{-1}$ (0.94 in $hr^{-1}$) precipitation event, 147 of 435 basins have likelihood of 50% or greater to produce debris flow; when using the 28 mm $hr^{-1}$ (1.1 in $hr^{-1}$) precipitation event, 215 of 435 basins have likelihood of 50% or greater to produce debris flows; and, when using the 40 mm $hr^{-1}$ (1.6 in $hr^{-1}$) event 312 of 435 basins have likelihood of 50% or greater to produce debris flows. In addition to the debris flow likelihood at the basin-scale, model outputs also include drainage network debris flow likelihood, or segment probability.

The USGS stream watch segments shown in the model results indicate the presence of drainages within and below the burn area that can be impacted by the combined effects of debris flows and floods generated from one or more tributaries. These are areas where a combination of runoff hazards may be present, and where flood hazards analyses should consider bulking factors for modeling the increase in runoff volume due to the contribution of sediment and debris.

[5] This precipitation input approximates historic debris flow triggering thresholds as discussed in the Debris Flow Precipitation Thresholds section of this report

For watersheds burned in the Soberanes Fire, these results give an indication of potential post-fire watershed response. It is important to note that the USGS probability and volume models provide debris flow hazards results for a single precipitation event. However, an additional hazard to be considered is the coupled result from several small debris flow or sediment-laden runoff events that load channel networks, followed by one large intense precipitation event that mobilizes this sediment as a large debris flow.

The USGS model results do not constitute a site-specific analysis of debris flow hazards. Additional on-the-ground evaluation should be conducted by qualified and licensed professionals where necessary. The model results are also limited in that they do not show hazards for basins that are less than 0.2 $km^2$ (~50 acres) in area, and do not specifically articulate hazards in areas where one or more tributaries may contribute flood and debris flows (watch segments), as discussed above. The hazards in burn areas that do not show a modeled result are therefore undefined by the model, but may be present. Similarly, for areas not shown as having a segment debris flow hazard associated with a drainage network, a hazard may still be present, yet undefined because the segment model results are limited based on the resolution of the input digital elevation (DEM) model. Additionally, other hillslope processes such as rock falls and debris slides are not included in the model results.

### 2.2.2 USGS Magnitude and Frequency Regression Model

The pre-fire and adjusted design flows for the affected watersheds were obtained from the U.S. Forest Service BAER Team hydrology analysis report (USFS, 2016a). Due to the lack of historic streamflow data in the affected watersheds and rapid assessment for the hydrology report, the U.S. Forest Service BAER team calculated design flow estimates based on a document titled “Methods for Determining Magnitude and Frequency of Floods in California, Based on Data through Water Year 2006” (Gotvald et al., 2012). This is an empirical model based on gauge data. These estimates assume pre-fire soil infiltration and ground cover conditions.

The BAER Team utilized “pour points” to analyze the contribution of runoff at basin outlets and to assess potential values at risk within the fire. These basins are various sizes and are determined by the desired outlet or “pour point” above a value at risk or area of concern. The BAER team calculated 32 “pour point” locations. Additional “pour point” locations were added by the WERT and analyzed at the 10-year return interval.

To determine the impact of the wildfire on first year post-fire peak flows, the total acres and acres burned at high, moderate, and low soil burn severity for each HUC 12 watershed was determined (see Table 2). Then a simple equation included in Foltz et al. (2009) was used to predict first year increases following the fire:

$$M = 1 + \left[\frac{Percent\ Runoff\ Increase_{(H+M)}}{100\%} \times \frac{(A_h + A_m)}{A_T}\right] + \left[\frac{Percent\ Runoff\ Increase_{(L)}}{100\%} \times \frac{A_L}{A_T}\right]$$

$$Q_{T10} = 2.0(Q_{10})\left[\frac{A_h + A_m}{A_T}\right] + \left(\frac{Q_{10} + Q_{25}}{2}\right)\left[\frac{A_L}{A_T}\right] + (Q_{10})\left[\frac{A_U}{A_T}\right]$$

$A_H$ = High burn severity area within the watershed (acre or $mi^2$)
$A_M$ = Moderate burn severity area within the watershed (acre or $mi^2$)
$A_L$ = Low burn severity area within the watershed (acre or $mi^2$)
$A_U$ = Unburned area within the watershed (acre or $mi^2$)
$A_T$ = Total watershed area (acre or $mi^2$)
$Q_{T10}$ = Total post fire adjusted discharge
$Q_{10}$ = 10-year return interval flow
$Q_{25}$ = 25-year return interval flow
M = Flow modifier

Limited studies and guidelines exist to determine the appropriate modifier or percent runoff increase for high and moderate soil burn severity. As stated in Foltz et al. (2009), US Forest Service BAER specialists have used a 100% runoff increase (i.e., a doubling of the runoff amount) for high/moderate soil burn severity areas in the first year after a severe wildfire. This simple approach appears reasonable for the Soberanes Fire and was used for post-fire flood analysis. The low burn 10-year peak was calculated as the average between the 10- and 25-year flows, or an average of a 20% increase in runoff due to low soil burn severity.

These post-fire flow increases are generally consistent with data presented by Moody and Martin (2001). They state that Rowe et al. (1949) has been used for post-fire flow modification evaluation in southern California for decades, and that for the first year after the wildfire, the ratio of post fire flow to pre-fire flow increases from 2 to 3 fold for less frequent, large magnitude storms (5 to 100-year recurrence intervals).

### 2.2.3 Surface Erosion Modeling Using ERMiT and GeoWEPP

The BAER team used the Erosion Risk Management Tool (ERMiT) (Robichaud, 2007) to model pre-fire and post-fire surface erosion (i.e., sheet and rill erosion) response by each soil map unit. ERMiT simulations for the 10-year recurrence storm are included in this report (Figure 8). In addition, Dr. Mary Ellen Miller (Research Engineer, Michigan Technological University) modeled surface erosion for a 10-year recurrence interval storm using GeoWEPP – the geographical interface for the Water Erosion Prediction Project (Renschler, 2003). The GeoWEPP model results are included in Appendix E. The surface erosion maps indicate watersheds that can be expected to generate the highest levels of hillslope erosion. This hillslope erosion can subsequently affect roads and drainage systems within the watershed, fill watercourses with high levels of sediment, and bulk flood flows with higher than typical sediment loads.

## 2.3 Field Methods

An initial calibration training was conducted by the WERT within the Palo Colorado area. The purpose of the training was to provide consistency in team member observations and documentation of potential hazard locations. An Excel spreadsheet titled “Burn Site Evaluation Summary” (Appendix D) was developed and used to compile notes during site specific observations. Data from the sheet were also collected using the Collector application on iPads and smart phones. The summary sheet logs the type of at-risk feature (e.g., a house or bridge), the address or general location, the Global Positioning System (GPS) location (WGS 84 datum), the type of hazard (e.g., flooding, debris flow, culvert plugging), the likelihood of hazard occurrence, and whether the hazard poses a risk to life-safety and/or property.

After the site specific training, the WERT broke into two teams and began assessing areas of concern. The WERT conducted a site-specific evaluation of Values at Risk (VARs) collected by the BAER team along with additional locations discovered during the evaluation. Areas where there were concentrations of residential homes, businesses, State Parks, and public infrastructure received the greatest attention. Field observations were conducted from September 7-12, 2016. The interior of the Soberanes burn area is in the Los Padres National Forest where campgrounds, trails, and scattered cabins were identified by the USDA Forest Service Burned Area Emergency Response (BAER) team. Road-related features, such as culverts and bridges, were surveyed at major drainage crossings. The California Department of Transportation (Caltrans) is identifying road-related high-value sites along State Highway 1.

The VARs assessed by the WERT include possible loss of life and property due to an elevated potential for increased streamflows, hyperconcentrated flows, debris torrents, debris flows, rock fall, and associated slope movement. VARs were assessed using the USGS post-fire debris flow modeling data for the 40 mm/hr 15-minute rainfall intensity (probability hazard), FEMA 100-year flood plain mapping, soil burn severity data, topography, aerial imagery, hillshade, slope, fire history, 2008 Basin-Indians Complex hazard points (SEAT, 2008), watershed boundaries (HUC-12[6]), DWR awareness floodplains, building clusters, ownership, and roads. Team members confirmed hazards based on site specific observations and interpretation of active geomorphic processes and landforms (Figure 3). When appropriate, team members noted preliminary or possible emergency protective measures.

**<u>It should be noted that the observations included in this report are not intended to be fully comprehensive and/or conclusive</u>**, but rather to serve as a preliminary tool to assist emergency responding agencies (e.g., CAL FIRE, County of Monterey, Caltrans, US Forest Service, Office of Emergency Services, Natural Resource Conservation Service, utility companies, and other responsible agencies) in the development of more detailed post-fire emergency response plans. **<u>It is intended that the emergency responding agencies will use the information presented in this report as a preliminary guide to complete their own more detailed evaluations and develop detailed emergency response plans and mitigations.</u>**

[6] A HUC-12 subwatershed is typically 15,000 to 40,000 acres in size.

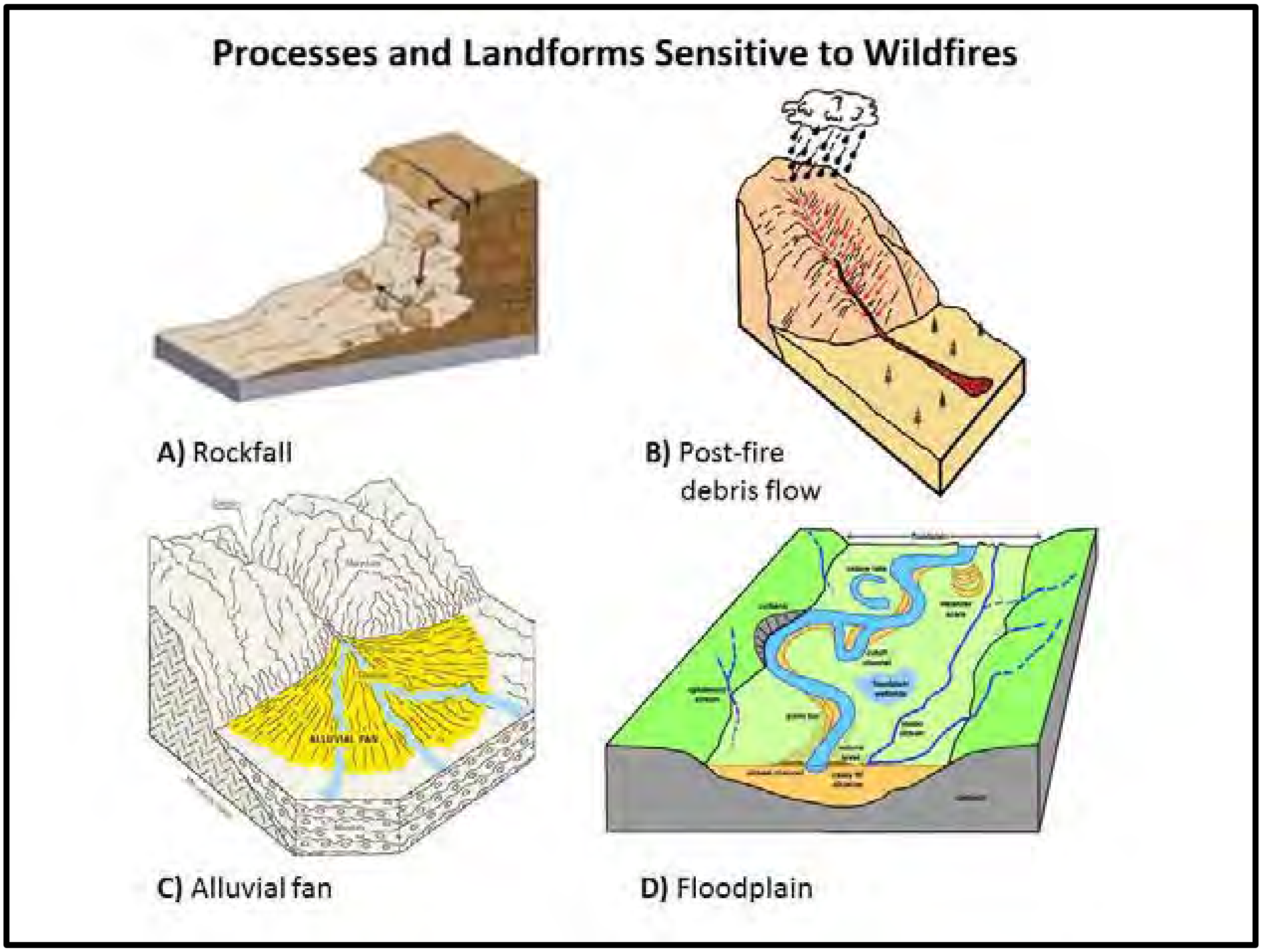


**Figure 3.** Geomorphic processes and landforms considered by WERT personnel to verify and assess hazards for VARs on the Soberanes Fire. VARs potentially subject to these geomorphic processes or located within or adjacent to these landforms were generally assigned a higher risk.

## 2.4 Scale of Analysis

The assessment area was broken into three units of watershed scale, or watershed tiers, for organization and ease of analysis:

- Tier 1 – Large watersheds
- Tier 2 – Sub-watersheds
- Tier 3 – "Pour point" watersheds

Communities and specific Values at Risk were assessed hierarchically using a nested watershed approach. The following figures (Figure 4 and Figure 5) describe how the various watersheds were nested.

The WERT looked at the potential for watershed-related hazards for the portion of the Soberanes Fire area covered by the USFS BAER Team (USFS, 2016). The one exception is that additional hydrologic assessment (i.e., pour point modeling) was performed for the Big Sur

River watershed using BARC data that was not field verified (Figure 1; note differences between BAER and WERT team analysis boundaries). Since active fire was in the upper Big Sur River watershed, the WERT members were not able field verify soil burn severity. However, it was necessary to use this data to look the potential for flooding along the Big Sur River adjacent to the community of Big Sur.

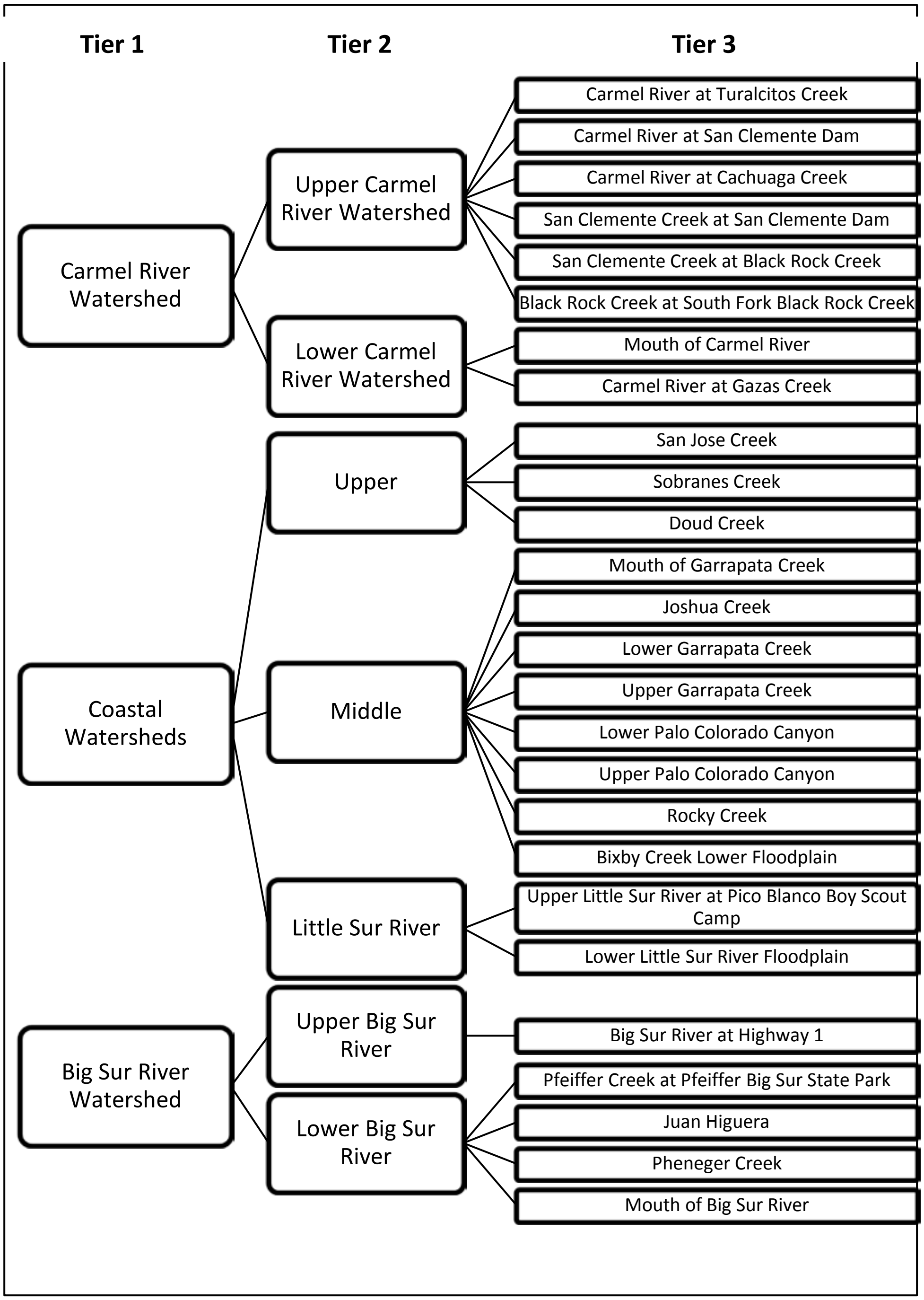


**Figure 4.** Tiered analysis levels


**Figure 5.** Tiered watershed map for the Soberanes Fire showing how the assessment area is broken into 1) large watersheds, 2) sub-watersheds, and 3) "pour point" watersheds.

## 3.0 Physical Setting

The following section discusses the physical setting of the Soberanes burn area pre- and post-fire. Since the footprint of the Soberanes Fire determines the specific area of description, the summary of the fire is discussed first.

### 3.1 Soberanes Fire Summary

The Soberanes Fire began on July 22, 2016 from an illegal campfire in Garrapata State Park, Monterey County. The CAL FIRE San Benito-Monterey Unit (BEU) took incident command on the first day and as the fire progressed south towards federal land within the first week, the USFS joined CAL FIRE in unified command. On the first day, the Soberanes Fire burned over 700 acres; the first week the fire burned over 27,000 acres; and within the first month it burned over 86,000 acres. At the time of development of this document, the fire had burned over 105,000 acres with 60% containment and it was still burning within containment lines to the south. Tje USFS has taken over incident command. There was one fatality associated with the fire that occurred during the first week, and at the date of this publication, 57 homes had been destroyed. It should be noted that since the homes were destroyed, the WERT did not specifically address hazards at these locations.

Detailed information is provided at: http://inciweb.nwcg.gov/incident/4888/

### 3.2 Vegetation

Vegetation in the burn area is a composite of grass lands, oak woodlands, chaparral, mixed hardwood/conifer, coast redwood and coastal scrub. Sudden oak death (*Phytophthora ramorum)* is also prevalent (http://www.suddenoakdeath.org/) within portions of the burn area, resulting in large amounts of down woody debris.

### 3.3 Rainfall/Climate

Average rainfall in the burn area ranges from 17 to 45 inches per year. Precipitation occurs almost entirely as rain, with rare occasions of snow at the highest elevations. Rain-on-snow events are possible but they typically are rare events. The fire area can be described as having a typical Mediterranean climate with warm dry summers and cool wet winters. Fog persists along the coast line in the summer. The 1-year recurrence interval, 15-minute rainfall magnitude ranges from 0.414 inches near Big Sur Lodge to 0.314 inches in the community of San Clemente Rancho (i.e., confluence of San Clemente and Black Rock Creeks). The 10-year recurrence interval, 15-minute rainfall magnitude ranges from 0.679 inches near Big Sur Lodge to 0.532 inches in the community of San Clemente Rancho (http://hdsc.nws.noaa.gov/hdsc/pfds/).

## 3.4 Regional Geologic Setting

The Soberanes Fire burn area is located in the central part of the Coast Ranges geomorphic province (CGS, 2002). This area contains several major bedrock units in two major structural blocks, both of which are west of the San Andreas fault (Rosenberg and Wills 2016, Appendix A). The Salinian block, which lies between the San Andreas fault and the Sur-Nacimiento fault, is comprised primarily of Paleozoic metamorphic rocks, named the Sur Series, and Mesozoic granitic rocks. Deep weathering of many Salinian block rocks has broken down mineral grains leading to "decomposed" or weakened rocks. For example, quartz-diorite (granitic) units (Map unit Kqd) tend to be dark gray, containing 20 to 25 percent mafic minerals (biotite and hornblende) that often tend to rapidly weather to clay minerals. Areas underlain by these rocks tend to be deeply weathered on higher slopes and overlain by weak colluvium. A large portion of the burn area is underlain by granitic rock. The granitic rocks are deeply weathered producing soils that are detachable and easily erodible. Soils and weathered bedrock on steep slopes in these areas can be expected to erode and transport sediment to watercourse drainages. The weak weathered rock and colluvium over much of the surface of the granitic rocks is prone to debris flows triggered by intense rainfall (Wills et al., 2001). West of the Sur-Nacimiento fault, the Nacimiento Block contains rocks of the Franciscan Complex. This area was attached to the North American Plate along a series of boundary faults, one of which is inferred to be the Sur-Naciemento fault. The Franciscan Complex is comprised dominantly of greywacke sandstone, with sand-sized material containing abundant feldspar and rock fragments within a matrix of silt and clay. Included in the Franciscan Complex are volcanic rocks, some of which include evidence that they were extruded in a deep marine environment. The rocks of the Franciscan Complex tend to be weak, intensely sheared and slightly metamorphosed.

Throughout the area bedrock units are locally overlain by Tertiary age continental and marine sedimentary rocks comprised on sandstone and mudstone, respectively, and Quaternary alluvial deposits. Quaternary units of significance are debris fan deposits mapped along and near the coast, from Carmel Highlands to the south of the Big Sur River (Map units Qydf and Qdf). A description of the geologic units within the Soberanes Fire area is included in the map explanation to the Regional Geologic Map (Appendix A).

Topography within the burn area ranges from gentle to very steep, with elevations ranging from about 200 feet above mean sea level along the western margin of the fire to an elevation of over 4,800 feet where the fire burned near Ventana Double Cone. Local extremes in relief occur in small catchments along the Big Sur River, where elevation changes measured from canyon mouth to crest of 3,000 feet occur over a map distance of less than 2 miles. The burn area lies below the elevation generally subject to rain-on-snow events, although snow may occasionally fall near the higher peaks. Much of the mountainous portion of the burn area drains into numerous watersheds that drain to the larger Big Sur River, Little Sur River, Carmel Valley River, and the Coastal Frontal Drainages (i.e., west facing slopes along the western portion of the burn area that drain into the Pacific Ocean via numerous west-flowing watercourses).

### 3.4.1 Post-fire Surficial Processes

The principal concern with the Soberanes Fire area is an increase in the potential for in-channel streamflow, hyperconcentrated flows, debris torrents, and debris flows derived from erosion. The primary mechanisms for this are increases in runoff resulting from reductions in interception resulting from the loss of live vegetation, reductions in infiltration due to the removal of soil cover, soil water repellency, and from the loss of mechanical support along stream channels. Also of concern is the long-term loss of mechanical support of hillslope materials that was provided by vegetation and vegetative litter.

In areas of high and moderate burn severity, water repellant soils can develop where waxy substances released by plant materials during hot fires follow thermal gradients into the soil and condense onto soil particles. Additionally the headwaters of these watersheds are very steep. Dry ravel (i.e., downslope mobilization of loose bedrock, soils, and sediment wedges accumulated behind vegetation removed during the fire) was observed on very steep slopes in numerous locations in the burn area. The loose materials may become mobilized into sediment-laden runoff during heavy rains, leading to the development of debris flows and debris torrents that may flow downstream from the watershed headwater source areas (Figure 6). The magnitude of post-fire damage will ultimately be determined by the intensity and duration of storms that impact the burn area, particularly during the winter of 2016-17.

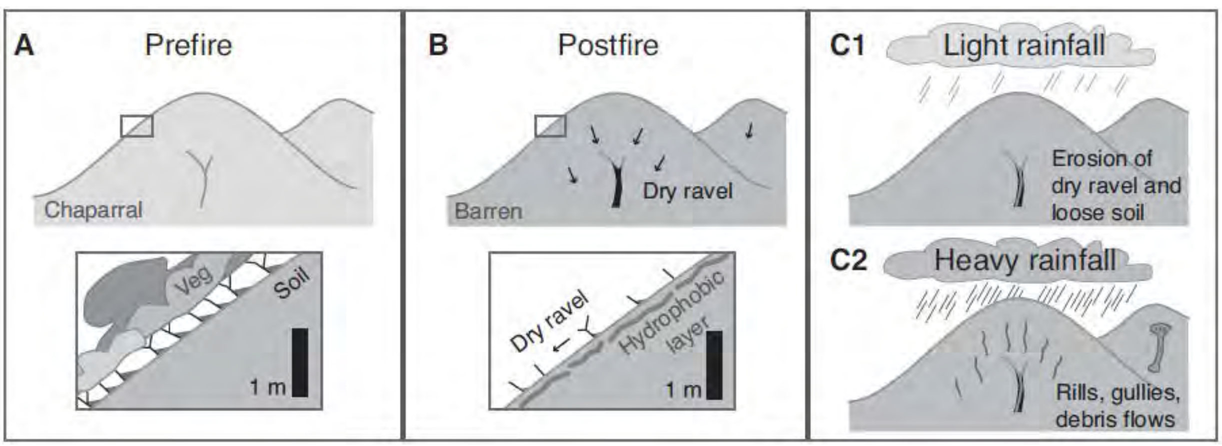


**Figure 6.** An illustration of the effects of wildfire on geomorphic processes for a steep, chaparral landscape. (A) Before a wildfire, the dense chaparral vegetation (veg) and organic debris retain sediment that had been mobilized downslope by diffusive processes. (B) During and immediately after a wildfire, the combustion of vegetation and organic debris above the ground reduces surface roughness and release retained soil as dry ravel, which accumulates as talus in colluvial hollows, hillslope toes, and stream channels. The high temperature of chaparral fire also creates a hydrophobic layer beneath the soil surface. (C1) and (C2) Sediment erosion and transport processes during post-fire rainfall are highly dependent upon rainfall intensity. Whereas light rainfall will result in the erosion of loose soil and dry ravel talus, heavy rainfall will generate overland flow at rates that can cut rills and gullies into the soil and potentially generate debris flows and induce downstream flooding (modified from Warrick et al., 2012).

### 3.4.2 Post-fire Debris Flow History

Records indicate that since the late 1800s there have been 10 large wildfires in the Big Sur area (Henson and others, 1996; Longstreth, 2013). Documentation of historic post-fire debris flow events in the general area affected by the Soberanes Fire is generally limited to locations near the Big Sur River along Pacific Coast Highway. However, studies on post-fire dry ravel erosion suggest that debris flows may have occurred in the Upper Carmel River following the Marble Cone Fire (Richmond, 2009). In the area of Julia Pfeiffer Burns State Park, numerous steep tributary watersheds issue on to debris fans. These fan-shaped landforms are formed where debris flows travel down the canyons of the small streams that drain into the Big Sur River (Wills et al., 2001). These fans provide a record of past debris flows and sediment-laden floodwaters and are also indicative of locations where future events may occur. Historic debris flows documented along the Big Sur River and south to Julia Pfeiffer Burns State Park indicate that since 1908 a minimum of nine documented debris flow events have occurred following wildfire (Cleveland, 1973; Jackson, 1977; JRP Historical Consulting Services, 2001; Wills et al., 2001; Longstreth, 2013).

After the Molera Fire burned approximately 4,300 acres in August of 1972, debris flows issued from Pfeiffer-Redwood Creek, Juan Higuera Creek, and Pheneger Creek on several occasions from October through November 1972. A partial volume estimate of 10,000 cubic yards was provided for some of these debris flows (Cleveland, 1973). Over this period, debris flows blocked Pacific Coast Highway and numerous homes and businesses were inundated with mud and water. At Big Sur Village, the November 15, 1972 debris flow damaged a cement block building, post office, mobile home, and 12 cars. The Basin Complex and Indians Fires burned the same area in June of 2008. A State Emergency Assessment Team (SEAT) documented the potential for burned watersheds to produce post-fire debris flows and recommended areas for emergency protective measures (SEAT, 2008). In April 2009 debris flows estimated to be 8,000 cubic yards in volume issued from several steep hillslopes that drain into Pfeiffer-Redwood Creek. Slopes were eroded with thousands of rills and gullies up to 1 foot wide and six inches deep. Pfeiffer-Redwood Creek was scoured to a depth of 12 feet, moving boulders 3 feet in diameter. As it flowed downstream, the debris flow plugged culverts, overtopped bridges, and flowed through the state park where it came to rest in a parking lot and State Route 1. Vehicles in the parking lot were damaged and Highway 1 was temporarily blocked with debris. Because this location had been identifed as a potential site for impact from post-fire debris flows, barriers (K-rails) had been placed to divert sediment from flowing into the State Park Lodge and offices (Longstreth, 2013). The following list provides a summary of the readily available documented post-fire debris flow history and associated precipitation and fire information along the coast from Big Sur River to Julia Pfeiffer Burns State Park.

| Date | Measured Precipitation | Fire Name |
|---|---|---|
| 1908, 1909, 1910 | (Precipitation unknown) | Unknown |
| 12 October 1972 | 0.82 in $hr^{-1}$ | Molera |

| | | |
|---|---|---|
| 15 October 1972 | 0.73 in $hr^{-1}$ | Molera |
| 15 November 1972 | 0.44 in 15 minutes | Molera |
| August 1978 | (Precipitation unknown) | Marble Cone |
| February 1986 | (Precipitation unknown) | Rat Creek - Gorda |
| 7 April 2009 | 0.84 in $hr^{-1}$ | Basin Complex - Indians |

### 3.4.3 Post-fire Debris Flow Precipitation Thresholds

Precipitation thresholds are developed by the identification of debris flow response in burned watersheds and comparing them with locally recorded rainfall at different durations (Cannon et al., 2008). The use of these empirically defined thresholds is a common way of representing debris flow potential in a recently burned area. Above the threshold, there is an increase in the likelihood of debris flow, whereas below the threshold, there is a lower likelihood of debris flow initiation. Instrumentation and measurements of post-fire debris flows in the Transverse Ranges has suggested that thresholds for periods less than 30 minutes are considered the best predictor of post-fire debris flows events (Kean et al. 2011; Staley et al. 2013). The USGS Post-Wildfire Landslides team and the National Oceanic and Atmospheric Administration - National Weather Service (NWS), typically work together to set thresholds used for rainfall alerts. Where possible, the NWS uses a radar and rain gages along with established rainfall thresholds that are known to trigger flash floods and debris flows, to issue watches and warnings for areas recently burned by wildfire.

The historic debris flow precipitation thresholds documented for the steep watersheds in the vicinity of the Julia Pfeiffer Burns State Park suggest that at 1-hour durations, precipitation on the order of 0.73 inches (19 mm) may be enough to generate debris flows. However, this comparison is under the assumption that burn extent and severity, topographic characteristics, and sediment availability, are similar between watersheds issuing past debris flows and those burned by the Soberanes Fire. In addition, intense, short duration precipitation, such as the 0.44 inch in 15 minutes (1-hour rate of 1.76 inches) in November 1972, may represent a precipitation threshold that if broadly distributed, would cause wide spread debris flow response in the burn area.

The USGS post-fire debris flow model's "design storm" precipitation inputs provide the flexibility to show debris flow model results at or near known thresholds as well as results for extreme rainfall. For this assessment the WERT agreed that the 28 mm $hr^{-1}$ is reasonably close to the hourly precipitation that has triggered debris flows. Furthermore, the 40 mm $hr^{-1}$ threshold, while not shown on the maps in Appendix B, represents an extreme precipitation condition where if broadly distributed could initiate widespread debris flows with associated magnitudes (i.e., volumes) exceeding historically documented events.

## 3.5 Regional Fire History

The northern third of the burn area has little to no recently recorded fire history, and this largely corresponds with the highest proportions of moderate and high soil burn severity. The southern two-thirds of the burn area have had multiple fires, and the recurrence interval of fire in this area is approximately 10-15 years (Figure 7).


**Figure 7.** Fire history map for the Soberanes Fire

## 3.6 Post-Fire Sediment Production

The pre-fire erosion hazard rating is generally high to extreme for the area affected by the Soberanes Fire (Appendix F). For assessing post-fire surface erosion hazard, ERMiT (Erosion Risk Management Tool)[7] was used to predict post-fire sediment production from sheetwash

[7] http://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/ermit/ermit.pl

and rilling. Model predictions for the 10-year recurrence interval runoff event suggest that the highest rates of surface erosion are from steep areas burned at moderate and high soil burn severity. Rates of surface erosion for the 10-year event are estimated to be greater than 5 to 10 tons per acre (Figure 8). These rates have a 10 percent probability of exceedance. Hillslope erosion in these watersheds erosion can be expected to affect roads and drainage systems, fill watercourses with high levels of sediment, and bulk flood flows with higher than typical sediment loads.

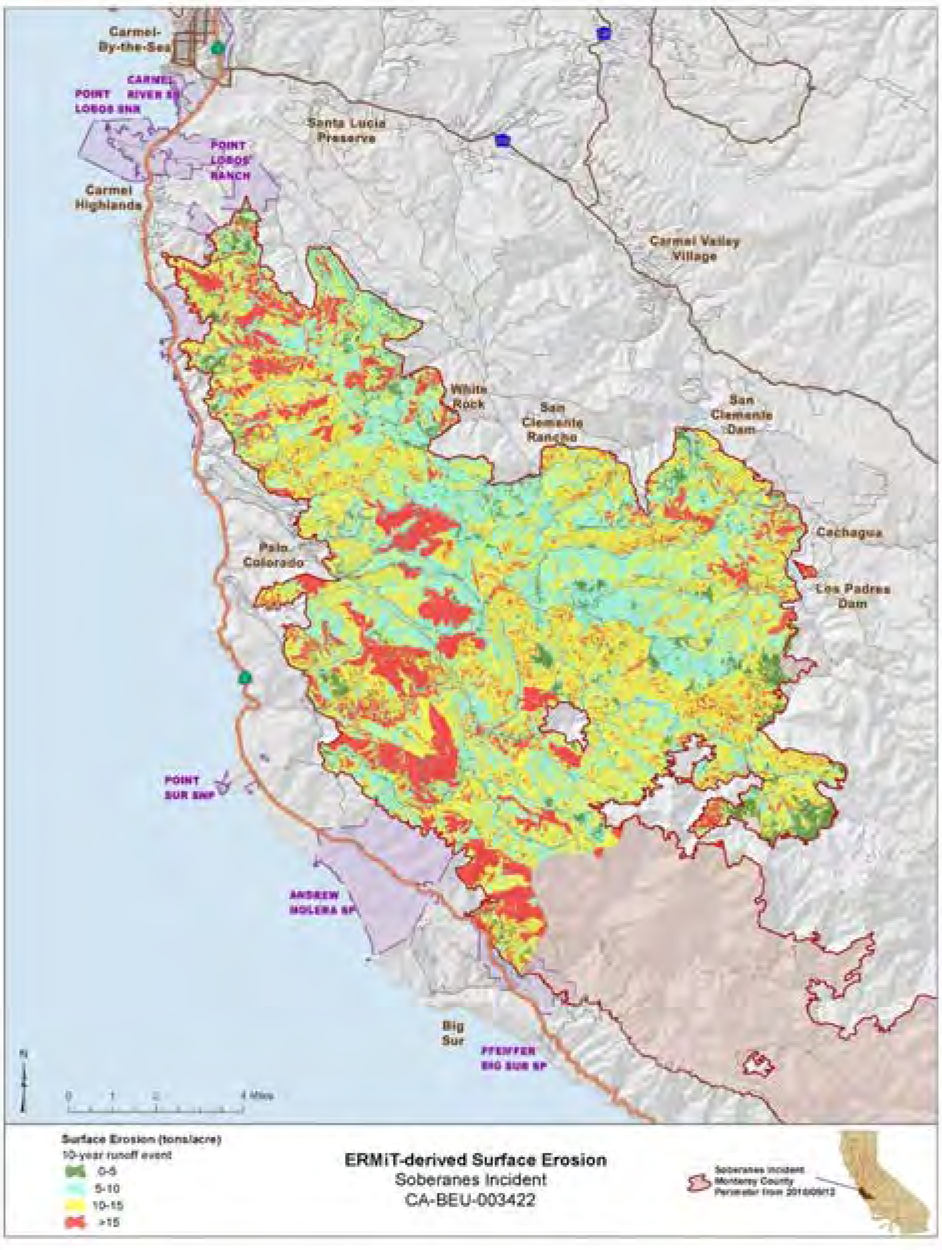


**Figure 8.** Predicted surface erosion rates for the 10-year runoff event within the Soberanes burn area.

## 3.7 Flooding

### 3.7.1 Flooding Information – Carmel Watershed

FEMA flood hazard maps were obtained for the Carmel River from the river mouth upstream to Los Padres Dam. FEMA flood hazard maps were also obtained for portions of Las Gazas Creek, including the community of Santa Lucia Preserve (Appendix B). DWR Awareness Floodplain maps were obtained for San Clemente Creek from San Clemente Dam (decommissioned) upstream along Dormody Road to the confluence of Black Rock Creek, and on the lower 2 miles of Pine Creek (Appendix B).

River levees and a dam are located downstream of the burn area and provide limited flood protection on the Carmel River. Levees are present on the lower Carmel River but are not certified by FEMA (FEMA 2009). Consequently, they do not provide flood protection for the 100-year flood event. The Los Padres Dam was constructed in 1949 for water supply purposes. The dam is not used for flood storage, although some flood storage is available when the reservoir is not full. The San Clemente Dam, located further downstream, was decommissioned and removed as of August 31, 2015. All elements of the decommissioning project, including a re-routing of the Carmel River as part of a fish passage restoration project, are scheduled for completion by October 31, 2016. Long-term sedimentation has averaged 1.4 $yd^3$/ac/yr (262 $m^3/km^2$/yr), based on bathymetric data (Minear and Kondolf 2009). Sedimentation in Los Padres Reservoir during the winter following the Marble-Cone fire of 1977 effectively doubled the long-term rate of reservoir filling (Hecht 1981, 2000).

Two USGS stream gages are located downstream of the burned area on the Carmel River. The first is approximately 3 miles upstream of the mouth of the Carmel River at Carmel (Gage No. 11143250) and has records from 1963 to present (Figure 9-Carmel Gage Plot).

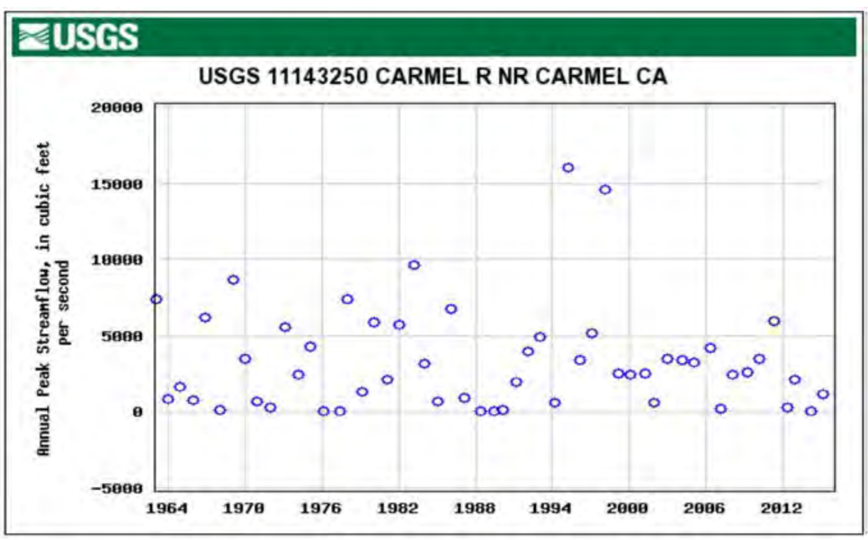


**Figure 9.** Annual peak flows on Carmel River near Carmel (USGS Gage No. 11143250). Peak flows for the gage were affected by upstream dams.

The second gage is located further upstream at Robles Del Rio in the Carmel Valley (Gage No. 11143200) and has records from 1957 to present (Figure 10). The highest peak flows recorded at both gages occurred in 1995 and 1998. The largest was in 1995 when a peak flow of 16,000 cfs was recorded at the Carmel gage (No. 11143250) and is roughly equivalent to a 30-year flood event.

The Flood Insurance Study (FEMA 2009) reports several years where flood damage occurred in portions of Monterey County, the most recent of which occurred in 1983, 1995 and 1998, but no specific information regarding flood damage is provided for the Carmel River.

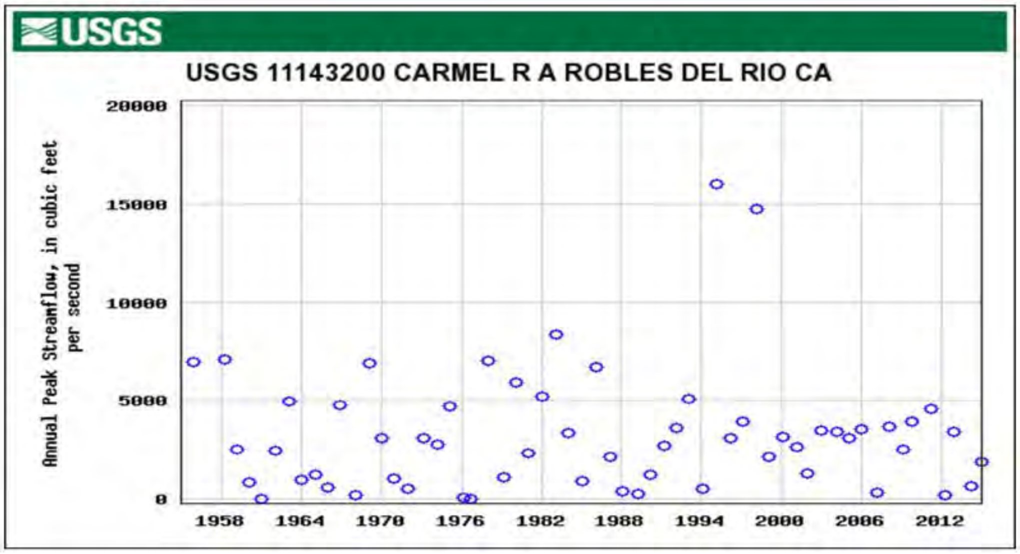


**Figure 10.** Annual peak flows on Carmel River at Robles Del Rio (USGS Gage No. 11143200). Peak flows for the gage were affected by upstream dams.

### 3.7.2 Flooding Information - Coastal Watersheds and Big Sur Watershed

Except on the lower parts of the Big Sur and Little Sur Rivers, no flood hazard maps are available on coastal watersheds draining from the burn area between San Jose Creek to the north and the Big Sur River to the south. FEMA flood hazard maps were obtained from the mouth of the Big Sur River to about 2 miles upstream of State Highway 1. Flood hazard maps were also obtained for the lowermost section of the Little Sur River from FEMA and for an additional 8 to 9 miles upstream of State Highway 1 from DWR Awareness Floodplain Maps (Appendix B).

An unregulated USGS stream gage is located approximately 1 mile upstream of State Highway 1 on the Big Sur River at Big Sur (Gage No. 11143250). Figure 11 shows annual peak flows recorded at the stream gage from 1950 to present. Larger peak flows occurred in 1978, 1995 and 1998, with the largest flood peak on record in 1978 at 10,700 cfs which is approximately a 200-year flood based on stream flow return interval calculations from Peak FQ http://water.usgs.gov/software/PeakFQ/.

The Flood Insurance Study (FEMA 2009) reports several years where flood damage occurred in portions of Monterey County, the most recent of which occurred in 1983, 1995 and 1998, but no specific information regarding flood damage is provided for the coastal watersheds described in this section.

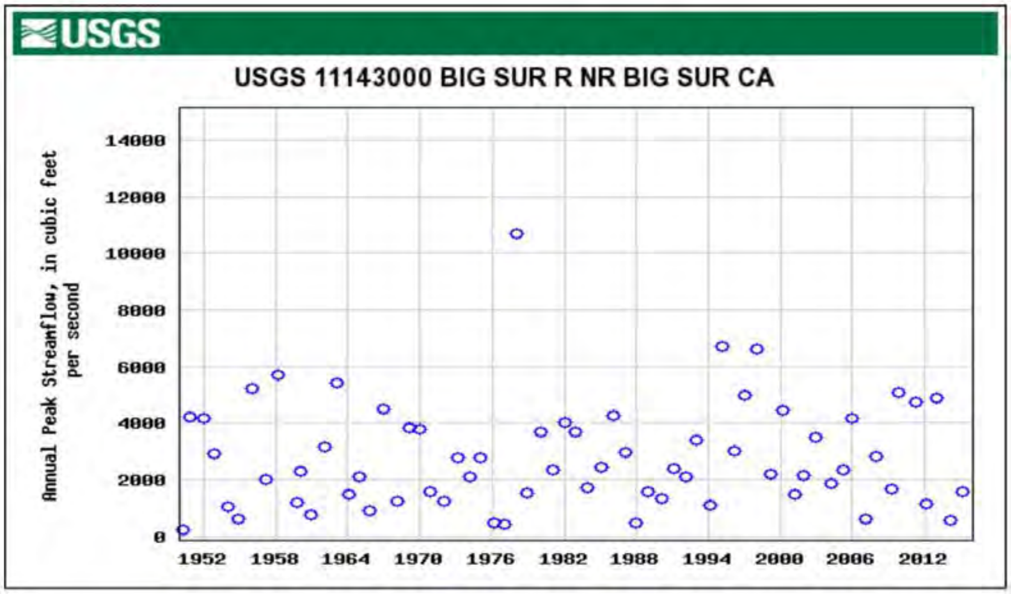


**Figure 11.** Annual peak flows on Big Sur River near Big Sur (USGS Gage No. 11143000).

## 3.8 Development and Key Infrastructure

Development in the assessment area is concentrated in the valley along the Carmel and Big Sur Rivers. A community is centered along the Palo Colorado Canyon Road. Small groupings of residences are also located along the bottom of some of the coastal drainages. In addition, small groupings of cabins are found in the upper Carmel River watershed. Two dams along the Carmel River are within assessment area as well.

## 3.9 Areas/Communities of Interest

3.9.1 **State Highway 1 -** The Highway traverses the length of the coast, west of the fire. The burn area drains through approximately 20 watercourse crossings along State Highway 1 from the Carmel River bridge in the north to the Big Sur River bridge in the south. Crossings consist of bridges, steel culverts and concrete box culverts. Maintenance of State Highway 1 falls under the jurisdiction of the California Department of Transportation (Caltrans).

3.9.2 **California State Parks** - Parks are located within and downstream of the burn area from Pfeiffer Big Sur State Park in the South to Carmel River State Beach. State Park facilities occur along watercourses that receive drainage from the burn area and have the potential to receive flood and debris flows. Facilities include camp grounds, picnic areas, road crossings, Big Sur

Lodge, parking lots, maintenance facilities and a waste water treatment plant. Specific State Park facilities are discussed below, based on their location within specific watersheds.

3.9.3 **The Santa Lucia Preserve –** The Santa Lucia Preserve is a 20,000 acre private preserve southwest of the Carmel River Valley. Most of the Preserve drains into the Lower Carmel River area, though a small portion drains to the Upper Carmel River area via San Clemente Creek. Three hundred home sites and several recreational facilities (golf courses, summer camps, etc.) are located within the Preserve. The Soberanes Fire encroached into some of the watersheds within the Preserve, creating a hazard for flooding and debris flows along San Jose Creek, Salsipuedes Creek, Los Gazas Creek, San Clemente Creek, and several tributaries.

3.9.4 **Carmel, Carmel Valley and Carmel Valley Village** - These communities are all located within the Carmel River Valley, which is a northwest to southeast oriented drainage that flows for approximately 16 miles from San Clemente Dam to the Pacific Ocean. The river valley varies in width from less than ¼ mile to more than ¾ mile at it widest point and is generally composed of unconsolidated alluvial sediments with mixtures of well sorted sands, gravels and boulders and is vegetated with a moderately dense to dense stand of cottonwoods and alders. The active river channel itself varies in width, is generally unconfined, with a gentle to moderate gradient. Based on a review of aerial photos and our site analysis, hundreds of residential homes exist within the floodplain of the Carmel River Valley. In addition, based on our review of FEMA flood maps, a large portion of the river valley is within the 100-year floodplain.

3.9.5 **White Rock** – White Rock is a private community and hunting club at the southern terminus of Robinson Canyon Road. The community consists of numerous cabins built on south-facing slopes that descend to Black Rock Creek and also along the base of Black Rock Creek. White Rock Lake is a man-made lake constructed on Black Rock Creek at the eastern end of the community. The Soberanes Fire burned the slopes upstream and opposite the White Rock community, creating a hazard for flooding and debris flows in the community along Black Rock Creek.

3.9.6 **San Clemente Rancho -** This is a private community and hunting reserve located at the eastern terminus of Dormody Road. The community generally consists of numerous cabins built on an alluvial fan at the mouth of Black Rock Creek and along a DWR Awareness Floodplain associated with San Clemente Creek. Trout Lake is a man-made impoundment constructed on San Clemente Creek at the eastern end of the community. The Soberanes fire burned most of the Black Rock Creek and South Fork Black Rock Creek watersheds that drain into the community, creating a hazard for flooding and debris flows in the community along Black Rock Creek and flooding along San Clemente Creek. Grim (2016) provides a detailed report on the life-safety hazards located in this area.

3.9.7 **Cachagua Syndicate Camp -** This is an 80-acre private community and commune located off Cachuaga Road along the segment of Carmel River between San Clemente Reservoir and Los Padres Reservoir. The community consists of numerous cabins constructed along the Carmel River floodplain. There are also privately owned properties/residences located upstream of the Syndicate Camp and along the hillslopes below the burned area. The Soberanes Fire burned a significant portion of the Carmel River drainage area upstream of the community, creating a hazard for flooding along Carmel River and debris flows along tributary channels.

3.9.8 **Cachagua –** This is a small community located at the confluence of Cachagua Creek and the Carmel River. Numerous residences and a community park facility are located within the FEMA 100-year floodplain along the Carmel River and at the confluence with Cachagua Creek. The Soberanes Fire burned a significant portion of the Carmel River drainage area upstream of the community, creating a hazard for flooding in this area.

3.9.9 **Lower San Jose Floodplain** - State Parks housing is located along the flood plain and is at risk to flooding. The house closest to the creek is no longer in use.

3.9.10 **Lower Garrapata/Joshua Creek Community** – This community consists of the Garrapata Creek watershed downstream from Wildcat Canyon (including the Joshua Creek watershed). The community is comprised of scattered residences and private properties, and residences are generally located low on the slopes in close proximity to Joshua Creek or Garrapata Creek. The Soberanes fire burned most of the Wildcat Canyon, Joshua Creek, and Upper Garrapata Creek watersheds, creating a hazard for debris flows and flooding along Garrapata Creek, Joshua Creek, and tributary channels.

3.9.11 **Palo Colorado –** This area consists of a community of homes centered along Palo Colorado Road in portions of the Garrapata, Palo Colorado and Rocky Creek watersheds. Numerous residences and crossing structures are within close proximity to the watercourses. Topography is generally steep narrow canyons with gentler slopes on the ridges and along the watercourse. Palo Colorado road is a single lane, county maintained road and the main egress road for the community. Significant portions of the upper watersheds were burned. There is past history of flooding along the road during large rain events. Significant tanoak mortality is visible along the watercourses, resulting in numerous down tan-oak trees within and adjacent to the channel. The watercourse crossings along the road may be susceptible to debris and flood flows.

3.9.12 **Bixby Flood plain Homes** - This group of residences is located along Bixby Creek, approximately 1 mile up-stream of Bixby Bridge/California State Highway 1. Vehicular access to the community is provided via the Coast Road, which intersects with State Highway 1, just north of Bixby Bridge. From the Coast Road, access to the community is provided through two wooden gates located where the Coast Road crosses Bixby Creek. The homes are scattered along the north and south sides of the creek, generally within 60- to -100 feet of the active channel. Flood terrace deposits flank the active channel and are generally 80- to 120- feet wide. Based on field observations, the homes within this community appear be at risk for potential flooding and debris flow hazards.

3.9.13 **Pico Blanco Boy Scout Camp –** The camp is located at the southeastern terminus of Palo Colorado Canyon Road along the Little Sur River. The site features numerous campgrounds, several permanent non-residential structures (lodge, trading post, boat house), a permanent caretakers residence, chapel, and dam/aquatics facility. Some facilities located along the Little Sur River are located within a DWR Awareness Floodplain, and others are located along tributary channels that drain the steep slopes adjacent to the camp. Palo Colorado Road is the sole vehicular access for the camp and has been subject to flooding during large rain events. The fire burned the slopes surrounding the camp and most of the Little Sur River drainage area upstream of the camp, creating a hazard of flooding along the Little Sur River and debris flows from tributary channels.

3.9.14 **Old Coast Road –** This road runs from the north side of the Bixby Creek Bridge, down across Bixby Creek, Up Sierra Creek, across Little Sur River, up the South Fork of Little Sur and back to Highway 1 near Molera State Park. All watersheds above the road were burned to some degree. Three crossings on the road could be subject to debris and flood flows, making the road impassable.

3.9.15 **Pfeiffer Big Sur State Park –** This State Park is situated along the banks of the Big Sur River below the confluence of Doland and Ventana Creeks. Depending on the severity of winter and spring rains, it is anticipated that the effects of the high and moderate burn severity in the watersheds of Doland Creek, Ventana Creek, Pfeiffer Redwood Creek, and the Upper Big Sur River will increase and magnify the size and intensity of flooding and debris flows on the Big Sur River within the park.

Campsites, roads, bridges and infrastructure within Pfeiffer Big Sur State Park are likely to sustain moderate to major damage. Particular concern is expressed along Pfeiffer Redwood Creek where post-fire debris flows impacted park grounds in 1973 (Cleveland, 1973) and in 2009 (Longstreth, 2013). Also of concern is the parks sewage treatment facility, scattered campgrounds, and associated structures. Bridges and culverts situated along Pfeiffer Redwood Creek are considered to be at risk for breaching or overtopping by flood waters or debris flows, with the resulting flows directed towards the park lodge (Big Lodge Sur) and parking lot. State Highway 1 opposite the entrance to the park may be undercut or removed by erosion (outside edge of meander) resulting from in-channel floods, hyperconcentrated floods, debris torrents, or debris flows on the Big Sur River.

3.9.16 **Big Sur Resorts -** Private campgrounds, cabins, resorts, shops, and other businesses are located along the bottom of Big Sur drainage. Photographs and anecdotal evidence obtained and viewed during the field visit suggest the site is subject to flooding, debris flows, and rock fall during heavy rains following fires. Cleveland (1973) documents flooding and damaging mudslides that occurred after the 1972 fires in the Big Sur watershed. It is anticipated that the effects of the high and moderate burn severity in the watersheds (Pheneger Creek, Juan Higuera Creek, Pfeiffer Redwood Creek, Upper Big Sur River) that drain to the developed Big Sur area will increase and magnify the size and intensity of flooding and mud flows, depending on the severity of winter and spring rains.

3.9.17 **Juan Higuerra Creek –** This creek drains to and under State Highway 1 via a bridge continuing through a culvert prior to entering Big Sur River. If the culvert plugs the creek can be diverted to what appears to be a small alluvial plain that contains scattered residential structures and the Big Sur Grange. Cleveland (1973) documents flooding and damaging mudslides that occurred after the 1972 fires in this area. It is anticipated that the effects of the high and moderate burn severity in the Juan Higuerra watershed will increase and magnify the size and intensity of flooding and the probability on debris flows, depending on the severity of winter and spring rains.

3.9.18 **Pheneger Creek** – This creek drains to and under Highway 1 via a metal culvert that will likely plug in the event of a debris flow event. The culvert drains to Big Sur Village containing business structures. Cleveland (1973) documents flooding and damaging mudslides that occurred after the 1972 fires in this area. It is anticipated that the effects of the high and moderate burn severity in the Juan Higuerra watershed will increase and magnify the size and intensity of flooding and the probability of debris flows, depending of the severity of winter and spring rains.

3.9.19 **Andrew Molera State Park –** This State Park is located along the floodplain near the mouth of the Big Sur River. The walk-in campground in the northern portion of the park is located on a floodplain that is about 10 to 15 feet above the active Big Sur River channel. Similarly the horse stables, barn, and residential structures at the southeast end of the park are located on a floodplain about 15 feet above the Big Sur River. Depending on the severity of winter and spring rains, it is anticipated that the effects of the high and moderate burn severity in the watersheds of Big Sur River will increase and magnify the size and intensity of flooding within the park.

## 4.0 Analysis and Observations

### 4.1 Soil Burn Severity

Rainfall intensity and the proportion of the watershed burned at moderate to high soil burn severity drives the potential for watershed response. Figures in Appendix B show the distribution of soil burn severity across the Soberanes Fire area. The proportion of “pour point” watersheds burned at low, moderate, high soil burn severity is summarized in Table 2.

**Table 2**. Soil burn severity summary for “Pour Point” watersheds

| Watershed "Pour Point" | % of Watershed | | | | | |
|---|---|---|---|---|---|---|
| | | | Burn Severity | | | |
| | Unburned | Burned | Low/Very Low | Moderate | High | No data |
| Carmel River @ Mouth | 83.3% | 16.7% | 8.0% | 8.2% | 0.3% | 0% |
| Carmel River @ Los Gazas | 79.9% | 20.1% | 9.7% | 9.9% | 0.4% | 0% |
| Carmel @ Tularcitos | 78.7% | 21.3% | 9.8% | 10.8% | 0.4% | 0% |
| San Clemente @ SC dam | 53.7% | 46.3% | 24.3% | 20.7% | 1.4% | 0% |
| San Clemente @ Black Rock | 96.1% | 3.9% | 2.7% | 1.2% | 0.0% | 0% |
| Black Rock Creek | 8.4% | 91.6% | 47.5% | 41.3% | 2.8% | 0% |
| Carmel @ SC Dam | 49.4% | 50.6% | 22.5% | 26.4% | 0.8% | 1% |
| Carmel @ Cachuaga | 57.2% | 42.8% | 16.1% | 24.9% | 0.6% | 1% |
| Big Sur River @ Mouth | 30.8% | 69.2% | 17.0% | 33.0% | 3.6% | 16% |
| Juan Higuera Creek | 13.6% | 86.4% | 12.4% | 74.0% | 0.0% | 0% |
| Phenegan Creek | 65.6% | 34.4% | 11.4% | 22.8% | 0.1% | 0% |
| Pfieffer Redwood Creek | 0.0% | 100.0% | 33.7% | 66.1% | 0.2% | 0% |
| Upper Big Sur River @ 101 Bridge | 23.4% | 76.6% | 18.7% | 35.0% | 4.3% | 19% |
| San Jose Creek | 68.4% | 31.6% | 18.7% | 12.6% | 0.3% | 0% |
| Malpaso Creek | 24.9% | 75.1% | 46.9% | 27.9% | 0.3% | 0% |
| Soberanes Creek | 9.5% | 90.5% | 40.6% | 49.3% | 0.6% | 0% |
| Doud Creek | 8.7% | 91.3% | 19.8% | 65.4% | 6.0% | 0% |
| Rocky Creek | 4.3% | 95.7% | 18.5% | 66.1% | 11.1% | 0% |
| Joshua Creek | 6.0% | 94.0% | 16.1% | 70.4% | 7.6% | 0% |
| Lower Garrapata | 12.2% | 87.8% | 9.4% | 71.2% | 7.2% | 0% |
| Upper Garrapata | 1.4% | 98.6% | 9.9% | 77.5% | 11.2% | 0% |
| Lower Palo Colorado | 61.4% | 38.6% | 5.2% | 32.7% | 0.7% | 0% |
| Upper Palo Colorado | 9.0% | 91.0% | 12.5% | 76.6% | 1.8% | 0% |
| Bixby Creek | 26.4% | 73.6% | 26.5% | 42.7% | 4.4% | 0% |
| Lower Little Sur | 11.9% | 88.1% | 28.3% | 59.3% | 0.3% | 0% |
| Upper Little Sur @ Boy Scout | 8.1% | 91.9% | 21.2% | 70.0% | 0.3% | 0% |

## 4.2 Flood Flow Model Results

Predicted percentage increases for a 10-year flood flow are shown below in Table 3. Refer to Appendix C for specific “pour point” discussion and Figure 5 (or Appendix B) for location of “pour point” watersheds.

**Table 3** –Increased flow from pre-fire condition summary. Post-fire increases greater than 50 percent are highlighted in red.

| ID | Watershed | Increased Flow From Pre-Fire Conditions* | Post Fire Adjusted Return Interval* |
|---|---|---|---|
| 1 | Pheneger Creek | 25% | 25 |
| 2 | Juan Higuera Creek | 77% | 50 |
| 3 | Pfeiffer Redwood Creek | 73% | 50 |
| 4 | Little Sur River | 65% | 50 |
| 7 | Rocky Creek | 81% | 100 |
| 8 | Palo Colorado Lower Canyon | 35% | 25 |
| 9 | Palo Colorado Upper RD crossing | 81% | 100 |
| 10 | Garrapatos RD | 90% | 100 |
| 11 | Mouth of Garrapata | 80% | 50 - 100 |
| 12 | Doud Creek | 75% | 25 - 50 |
| 17 | Soberanes Creek | 55% | 25 - 50 |
| 18 | Malpaso Creek | 39% | 25 |
| 19 | Carmel River | 19% | 25 |
| 20 | San Clemente Creek/San Clemente Dam | 29% | 25 |
| 23 | Carmel @ Cachuaga | 16% | 25 |
| 21 | San Jose Creek | 19% | 25 |
| 25 | Middle Little Sur | 74% | 50 - 100 |
| 27 | San Clemente Creek/Dormody RD | 3% | 10 |
| 28 | Black Rock Creek | 54% | 25 - 50 |
| 30 | Bixby Creek on Coast Road | 61% | 25 - 50 |
| N1 | Carmel River Watershed | 15% | 25 |
| N2 | Carmel River Upstream of Las Gazas Creek | 17% | 25 |
| N3 | Carmel River Upstream of Tularcitos Creek | 18% | 25 |
| N4 | Joshua Creek | 82% | 50 |
| N5 | Lower Garrapata | 81% | 50 - 100 |
| N6 | Upper Big Sur River @ 101 Bridge | 57% | 50 |
| N7 | Big Sur River @ Mouth | 53% | 25 - 50 |

** Calculated for the 10 year return interval*

## 4.3 Debris Flow Model Results

Refer to the USGS model results map in Appendix B and discussion in Appendix C and the Basin Flow Probability Map in Appendix H.

## 4.4 Emergency Determination - Exigencies

The emergency to values at risk from geologic and hydrologic hazards (i.e., debris landslides, debris flows, rockfall, and flooding) caused by the fire include adverse effects for the health and safety of people, residences, roads and bridges within the wildfire area. Of particular concern is the potential risk for loss of life and property in moderate to high soil severity burn areas within the wildland/urban interface. Based on the WERT field observations, particular concern for the potential risk for loss of life and limb downslope of high and moderate soil severity burn areas exist at the Big Sur, Lower Bixby Creek community, Palo Colorado communities, Garapata/Joshua Creek communities, and San Clemente Rancho.

**Table 4:** Exigency summary table for the 2016 Soberanes Fire

| **Resources at Risk** | **Likelihood** | **Consequence** | **Risk Rating** |
|---|---|---|---|
| Campgrounds, facilities, and structures on the **Big Sur River** (flooding) | Possible to Likely | Medium to High | Medium to High |
| Residences and State Highway 1 within and near **Juan Higuera Creek** (debris flow) | Possible to Likely | High | High |
| Residences, State Highway 1, and Big Sur near **Pfeiffer Redwood Creek** (debris flow) | Likely to Very Likely | Medium to High | High to Very High |
| Residences, structures, State Highway 1 near **Pheneger Creek** (debris flow) | Likely to Very Likely | Medium to High | High to Very High |
| Residences located near or with the lower reach of **Bixby Creek** (debris flow and/or flooding) | Possible to Likely | Medium to High | High |
| Residences and road infrastructure in the Palo Colorado Communities drained by **Garrapato Creek, Palo Colorado Canyon, Rocky Creek, Turner Creek, Mill Creek** (debris flow and/or flooding) | Likely to Very Likely | Medium to High | High to Very High |
| Residences and road infrastructure in the Palo Colorado Communities drained by **Joshua Creek and Garrapato Creek** (debris flow and/or flooding) | Possible to Likely | Medium to High | High |
| Residences and road infrastructure in the San Clemente Rancho drained by **South Fork Black Rock, Black Rock, and San Clemente Creeks** (debris flow and/or flooding) | Possible to Likely | Medium to High | High |

*****qualitative ratings based upon observed field conditions by licensed professionals.

## 4.5. General Recommendations

- <u>Early Warning Systems</u>

Existing early warning systems should be used and improved such that residents can be alerted to incoming storms, allowing enough time to safely vacate hazard areas. In areas where cell reception is poor or non-existent methods should be developed to effectively contact residents.

This may include contacts made by mutual water companies located within the general area (B. Hecht, Balance Hydrologics, Berkeley, CA, personal communications.

Currently, Monterey County has an ALERT flood warning system in place that may need repair or upgrading after the Soberanes Fire (see below and: http://www.mcwra.co.monterey.ca.us/flood_warning/ALERT_system.php

Flood Warning

## ALERT Flood Warning System

Following the Marble Cone fire of 1977, Monterey County began the installation of one the first ALERT flood warning networks anywhere. ALERT (Automated Local Evaluation in Real Time) is a communications protocol that was developed by the National Weather Service in the 1970's. ALERT is a reliable, low cost method of transmitting environmental data from remote sites to a central database in real time. ALERT compatible hardware and software has continued to improve and is currently being used for environmental monitoring and flood warning systems throughout the world.

The current Monterey County ALERT flood warning system is operated and maintained by the Monterey County Water Resources Agency. The system consists of approximately 50 remote sites located throughout the major watersheds of Monterey County. These remote sites measure a variety of environmental factors including rainfall, water level, and air temperature that are used to forecast flooding and monitor storm events..

Data from the Monterey County flood warning system can be monitored by MCWRA staff through a secure web based interface from any computer or mobile device with internet access and a web browser. The modern web based system, in conjunction with the redundant ALERT radio backbone, allow reliable access to real time hydrologic data in even the worst storm conditions. Data from the Monterey County flood warning system is used to support flood monitoring operations by the Water Resources Agency as well as the National Weather Service, and the California Nevada River ForecastCenter.

Emergency-response and public-safety agencies are faced often with making decisions and deploying resources both well in advance of each coming winter storm and during storms themselves. Information and methodology critical to this process is provided for by the USGS open file report OF10-1039 that can be accessed at: http://pubs.usgs.gov/of/2010/1039/pdf/OF10-1039.pdf.

For post-fire debris flow hazards, warnings with practical lead times of several hours must come from a combination of weather forecasts, rainfall measurements of approaching storms, and debris-flow triggering thresholds. The USGS has worked together with the National Weather Service (NWS) to provide guidance for post-fire debris flow thresholds that may be used by the NWS for “watch” and “warning” notifications: http://landslides.usgs.gov/hazards/warningsys.php

- Road Drainage Systems and Storm Patrols

Existing road drainage systems should be inspected by the appropriate controlling agency to evaluate potential impacts from floods, hyperconcentrated floods, debris torrents, debris flows and sedimentation resulting from storm events. Additional modeling of sedimentation can be done through the use of sedimentation models such as ERMiT and WEPP.

- Structure Protection

Possible structure protection measures should be coordinated through Monterey County OES and the NRCS. Debris flow mitigation measures can consist of K--Rails, H-beams with wood lagging, plywood, sand bagging, and Muscle Wall installations. For the 2008 Basin-Indians Complex, limited options were available in some locations due to access issues and access-driven costs (Fisher et al. 2009), and these could be significant constraints for post-fire construction work for some parts of the Soberanes Fire footprint and downstream locations.

- Temporary Housing

When there is need for temporary housing or new building construction for residents displaced by the fire, site-specific evaluation of hazards for temporary housing should be conducted by a qualified professional and in accordance with the local lead agency . The following factors should be considered as part of the evaluation.

On hillslopes above potential temporary housing and building sites:

Could runoff from the hillslope concentrate in swales and small drainages and flow onto the site, and flood or otherwise damage the proposed structure, or present a life-safety hazard?

- ✓ Is the hillslope behind the structure steep and erodible, where rilling, gullying, or shallow failures could deliver a sufficient volume of sediment and debris to damage the proposed structure or pose a life-safety hazard?
- ✓ Are large rocks, boulders, or other material present on the slope that pose a rock- or debris fall hazard that could impact the proposed structure, or present a life-safety hazard?
- ✓ Is there evidence of recent or impending erosion or mass wasting that could damage the proposed structure or pose a life/safety hazard (e.g. debris torrents/flows, deep-seated slides or slumps)?

On hillslopes below potential temporary housing and building sites:

- ✓ Is there evidence of recent or impending fill slope landslide-type failures that indicate an elevated risk of building pad failure?
- ✓ Is the building pad located above a watercourse where normal- or flood flows could potentially erode the toe of the slope and trigger failure?

If any of these conditions are present, then mitigations need to be implemented, or alternative sites need to be identified and evaluated. Technical experts such as licensed engineers or geologists may be needed to support the evaluation.

## 4.6 Localized Observations and Recommendations

### 4.6.1 Lower Carmel

#### 4.6.1.1 Lower Carmel @Mouth

- **Specific Observations -** One specific observation (VAR 569) was made in the mouth of the Carmel River watershed. This consists of a bathroom and parking lot at Carmel State Beach. The parking lot and bathroom structure are located in the FEMA 100-year flood zone. The parking lot and bathroom structure appear to be at a moderate risk of flooding. During our evaluation we spoke with a representative of California State Parks (Mr. John Hiles) who indicated that the parking lot regularly floods. Mr. Hines indicated that sand bagging is usually used to minimize flooding of the parking lot and bathroom structure.
- **General Recommendations**
  - Develop flood protection measures for the Carmel State Beach parking lot and bathroom structure.
  - Even though the Carmel River is not modeled as a “watch stream”, because the area drains a large area flood hazards analyses may need to consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris.

#### 4.6.1.2 Gazas Creek @ Carmel River

- **Specific Observations -** Five specific observations were made in the Carmel River – Las Gazas watershed (VAR 144-147 and 162). Four of the locations consist of road watercourse crossings (two culverts, a bridge and a footbridge) in the Santa Lucia Preserve. The risk to property and life at these locations appears low. The final location consists of residences located in the FEMA 100-year flood zone near the confluence of Las Gazas Creek and the Carmel River. Because of the potential for increased flooding, the risk to life and property was recorded as high.
- **General Recommendations**
  - Develop an early warning system for residents in the FEMA 100-year flood zone (VAR 162).
  - Develop a storm watch patrol for points in the Santa Lucia Preserve (VAR 144 - 147) so that watercourse crossings may be observed for blockage and cleaned out during and after storms.

### 4.6.2 Upper Carmel

#### 4.6.2.1 Carmel River @Tularcitos Creek

- **Specific Observations -** One specific observation (VAR 200) was made within the Carmel River at Tularcitos pour point. This consists of a fish hatchery that is operated by the Monterey Peninsula Water Management District (MPWMD). The hatchery located in close proximity to the FEMA 100-year flood zone was assessed to be at a relatively low risk from flooding.

#### 4.6.2.2 San Clemente

- **Specific Observations**
  - San Clemente Rancho Community (VAR 148-152) It is anticipated that the effects of the generally low and moderate burn severity of the slopes in the Black Rock Creek watershed may increase and magnify the size and intensity of flooding, debris flows, and mud flows depending on the severity of the winter and spring rains. A number of homes and associated infrastructure were observed on an alluvial fan at the base of Black Rock Creek and may be impacted by potential debris flow and/or flooding. A number of homes, associated infrastructure, and a community center were noted in close proximity to San Clemente Creek from the confluence with Black Rock Creek to Trout Lake (a man-made lake on San Clemente Creek). These features may be impacted by potential flooding. An early warning system tied to prediction of incoming storm events will allow inhabitants to vacate buildings prior to triggering rainfall events. Storm patrol between and during large rainfall events in order to keep culverts and drainage structures functional can help maintain road access.
  - White Rock Community (VAR 153-154) It is anticipated that the effects of the generally low and moderate burn severity of the slopes in the Black Rock Creek watershed may increase and magnify the size and intensity of flooding and debris flows, depending on the severity of the winter and spring rains. A residence and a bridge that appears to be the only access to several residences upstream are located in the floodplain of Black Rock Creek and may be impacted by potential flooding and/or debris flows. An early warning system tied to prediction of incoming storm events will allow inhabitants to vacate buildings prior to triggering rainfall events. Storm patrol between and during large rainfall events in order to keep culverts and drainage structures functional can help maintain road access.
- **General Recommendations**
  - A bulking factor for flow analysis should be considered for “watch stream” segments when designing mitigations. It has been our experience that a bulking factor of at least 50 percent has been used in other post-fire responses.
  - White Rock Community, Rancho San Clemente Community (VAR 148-154): Early warning system, storm patrol.

#### 4.6.2.3 Carmel River @ San Clemente Dam

- **General Observations**
  - (VARs 155, 156, 159, 163, 201) It is anticipated that the effects of the generally moderate burn severity of the slopes that drain into the Carmel River may increase and magnify the size and intensity of flooding, depending

on the severity of the winter and spring rains. A number of homes, cabins, and associated infrastructure were noted in close proximity to the Carmel River in this area. These features may be impacted by potential flooding. An early warning system tied to prediction of incoming storm events will allow inhabitants to vacate buildings prior to rainfall. Storm patrol between and during large rainfall events in order to keep culverts and drainage structures functional can help maintain road access.

  - (VARs 157-158) It is anticipated that the effects of the generally low and moderate burn severity of the northeast facing slopes that drain into the Carmel River may increase the potential for debris flows, depending on the severity of the winter and spring rains. A residence and a culvert along a road that appears to be the only access route are located across or in close proximity to channels and may be impacted by potential debris flows. An early warning system tied to prediction of incoming storm events will allow inhabitants to vacate buildings prior to triggering rainfall events. Storm patrol between and during large rainfall events in order to keep culverts and drainage structures functional can help maintain road access.
- **General Recommendations**
  - Because "watch stream" flood hazards are present, any flood analyses should consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris.
  - An early warning system tied to predicted storm events should be developed for these areas. Because cell reception is poor in these areas, a reverse 911 or "Nixle" system may not provide an adequate warning system.

#### 4.6.2.4 Carmel River @ Cachuaga

- **General Observations** - USGS modeled "watch streams" drain into the Los Padres Dam.
- **Specific Observations** - None. No specific features or locations were identified.
- **General Recommendations**- Because "watch stream" flood hazards are present, any flood analyses should consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris.

### 4.6.3 Upper Coastal Waterheds

#### 4.6.3.1 San Jose Creek

- **Specific Observations**
  - (VAR 143 and 630) This group of residences is located at the base of White Rock Ridge, within the headwaters of San Jose Creek, which experienced low to high burn severity. Specifically, both of the homes have been constructed on debris/alluvial fans that drain the burned areas. It is anticipated that the effects of the low to high burn severity in the watershed that drains to the homes will increase and magnify

the size and intensity of rainfall runoff that could lead to debris flows, and mud flows, depending on the severity of winter and spring rains. Such flows and flooding may likely impact the residences.

- (VAR 570) This point is located in Carmel River State Beach, where San Jose Creek drains into the Pacific Ocean. It is anticipated that the effects of the low to high burn severity within the headwaters of the watershed will increase and magnify the size and intensity of rainfall runoff that could lead to flooding depending, on the severity of winter and spring rains. Such flooding may likely impact the existing residential structures within low lying areas.

- **Recommendations**
  - Follow recommendations in Appendix D.

##### 4.6.3.1.1 Malpaso, Soberanes and Doud Creeks

- **Specific Observations**
  - VAR 165 is located within the mid-stream portion of the Malpaso Creek watershed, which experienced low to moderate burn severity. Specifically, this point is located adjacent to the Malpaso Water District facilities that consist of several wells and a conveyance pipeline. It is anticipated that the effects of the low to moderate burn severity in the watershed that drains towards the Malpaso Water District facilities will increase and magnify the size and intensity of rainfall runoff that could lead to flooding, debris flows, and mud flows, depending on the severity of winter and spring rains. Such flows and flooding may likely impact the existing infrastructure.
  - Refer to Appendix D for VAR 571 and 572.
- **Specific Recommendations**
  - Follow specific recommendations in the Appendix D.

### 4.6.4 Middle Coastal Watersheds

#### 4.6.4.1 Joshua Creek/Lower Garrapata Creek

- **General Observations**
- (VARS: 109-126) This group is located at the base of the headwaters of Joshua Creek which experienced low to high burn severity. Dry ravel was observed on the very steep slopes (greater than 100%) that form the upper headwater slopes. It is anticipated that the effects of the low to high burn severity in the watershed that drains to the residential area will increase and magnify the size and intensity of rainfall runoff that could lead to flooding, debris flows, and mud flows, depending on the severity of winter and spring rains. Such flows and flooding may likely impact homes and existing infrastructure, including a bridge that provides access to a residence, culverts (some of which are plastic and have melted), the road prism and several water tanks that were placed within the active channel.
- (VAR 127-131) This group of residences is located near the confluence of Joshua and Garrapata Creeks which experienced moderate burn severity. It

is anticipated that the effects of the moderate burn severity in the watershed that drains towards Lower Garrapata Creek will increase and magnify the size and intensity of rainfall runoff that could lead to flooding, depending on the severity of winter and spring rains. Such flows and flooding may likely impact the existing residential structures that are located within the floodplain, as well as infrastructure, including watertanks.

- **General Recommendations**
  - VAR 109-126, Perform storm patrols and monitor road drainage infrastructure. Replace any existing plastic culverts that were destroyed in the fire.
  - VAR 127-131, Perform storm patrols and monitor road drainage infrastructure.

### 4.6.4.2 Palo Colorado Community

- **General Observations**
  (see site-specific descriptions for VARs 100-108, 132-141, 500-550 and 625-627; Appendix D).

  It is anticipated that the effects of the generally moderate burn severity of the slopes in the greater Palo Colorado community will increase and magnify the size and intensity of flooding, debris flows, and mud flows, depending on the severity of the winter and spring rains. The greater Palo Colorado community includes a group of residences in or in close proximity to channels that are subject to potential debris flows and/or flooding. This includes residences along Palo Colorado Canyon Road, in the Green Ridge Road area, in the Hoist area, and in the Garrapatos Road area. Additionally, a number of residences in these areas are accessed via watercourse crossings (i.e., bridges, culverts) that may be impacted by potential flooding and debris flows. Palo Colorado Canyon Road serves as the primary ingress/egress route for all of these communities and it was observed that this road crosses numerous watercourses that may be impacted by potential flooding and/or debris flows. An early warning system tied to prediction of incoming storm events will allow inhabitants to vacate buildings prior to triggering rainfall events. Storm patrol between and during large rainfall events in order to keep culverts and drainage structures functional can help maintain road access. Clearing the channel and floodplain of debris at recommended locations can improve flow and prevent debris from becoming mobilized in debris flows or floods, which can help to maintain functionality of drainage structures.
- **Specific Recommendations:**
- Follow specific recommendation for VARs provided in Appendix D.
- **General Recommendations:**

- Because “watch stream” flood hazards are present, any flood analyses should consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris.
- An early warning system tied to predicted storm events should be developed for the Palo Colorado and Lower Bixby communities. This includes residential structures and road drainage features along Palo Colorado Road. Because cell reception is poor in these areas a reverse 911 or “Nixle” system may not provide an adequate warning system.

#### 4.6.4.3 Bixby Creek

- **General Observations**
  - (VAR 552-561) This group of residences and a bridge is located at the base of the headwaters of the Bixby Creek, which experienced moderate to high burn severity. Dry ravel was observed on the very steep slopes (greater than 100%) that form the upper headwater slopes along Long, Skinner and Mescal Ridges. It is anticipated that the effects of the moderate to high burn severity in the watershed that drains to the residential area will increase and magnify the size and intensity of rainfall runoff that could lead to flooding, debris flows, and mud flows, depending on the severity of winter and spring rains. Such flows and flooding may likely impact homes and existing infrastructure, including several bridges that provide access to some of the residences.
  - (VAR 603-612) This group of culverts and one residence is located near the base of the headwaters of the Sierra Creek, which experienced moderate burn severity. Dry ravel was observed on the very steep slopes (greater than 100%) that form the upper headwater slopes along the south side of Mescal Ridge. It is anticipated that the effects of the moderate burn severity in the watershed that drains along the Coast Road will increase and magnify the size and intensity of rainfall runoff that could lead to flooding, debris flows, and mud flows, depending on the severity of winter and spring rains. Such flows and flooding may likely impact the existing infrastructure, including the culverts and road prisms.

- **General Recommendations:**
  - Because “watch stream” flood hazards are present, any flood analyses should consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris.
  - An early warning system tied to predicted storm events should be developed for the Palo Colorado and Lower Bixby communities. This includes residential structures and road drainage features along Palo Colorado Road. Because cell reception is poor in these areas, a reverse 911 or “Nixle” system may not provide an adequate warning system.

### 4.6.5 Little Sur

#### 4.6.5.1 Upper Little Sur Boy Scout Camp

- **General Observations:**
  The Pico Blanco Boy Scout Camp (VAR 101) is located at the base of the headwaters of the Little Sur River, which experienced high and moderate burn severity. Dry ravel was observed on the very steep slopes (greater than 100%) that form the upper headwater slopes that overlook the camp area. It is anticipated that the effects of the high and moderate burn severity in the watershed that drain to the camp area will increase and magnify the size and intensity of rainfall runoff that could lead to flooding, debris flows, and mud flows, depending on the severity of winter and spring rains. Such flows and flooding may likely impact existing infrastructure, including a concrete dam, boat house, spring box and water filtration system, and campgrounds located along the bottom of the Little Sur River or below steep slopes that drain to the river. The access road leading to the Boy Scout Camp that crosses several streams experienced moderate burn severity; it is evaluated and commented on in the USFS BAER report (USFS, 2016). Their report contains specific recommendations regarding the access road that can be found at the following link (http://inciweb.nwcg.gov/incident/5017/). The WERT did not evaluate the camp access road. If the road is damaged, access may be cut off from the camp during and following heavy rains. Also, during the WERT visit, the team met an aborist (Mr. Frank Ono, F.O. Consulting) who was evaluating tree fall hazard. Mr. Ono indicated that there appears to be a significant tree fall hazard in the camp area.
- **General Recommendations**
  - The Boy Scout Camp should be closed during storm events in order to minimize potential risk to life.
  - Because the Little Sur River is modeled as a “watch stream” a bulking factor for flow analysis should be considered when designing mitigations. It has been our experience that a bulking factor of at least 50 percent has been used in other post-fire responses.
  - Follow recommendations provided in the BAER analysis of the camp access road.
  - Follow recommendations regarding tree hazards (F.O. Consulting).

#### 4.6.5.2 Lower Little Sur

- **Specific Observations:**
  Refer to VAR 613 (see Appendix D). Only one specific observation was made in the lower Little Sur River watershed. This consists of a bridge crossing of the river. The bridge appeared to span the river and is located relatively high over the river. There appeared to be a low risk of damage to the bridge.

Conducting storm patrols after winter storms will enable evaluation of whether the bridge is at risk of being blocked with debris or damaged.

- **General Recommendations:**
  - Conduct storm patrols of the bridge during and following storm events.
  - Because the Little Sur River is modeled as a "watch stream," flood hazards analyses may need to consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris.

### 4.6.6 Big Sur River

- **Specific Observations:**
  - See site-specific descriptions for points 562-568, 573-581 and 614-624, Appendix D).
  - Historic debris flows documented along the Big Sur River and south to Julia Pfeiffer Burns State Park indicate that since 1908 a minimum of nine debris flow events have occurred following wildfire (Cleveland, 1973; Jackson, 1977; JRP Historical Consulting Services, 2001; Wills et al., 2001; Longstreth, 2013) with the most recent debris flows occurring after the 2008 Basin-Indians Complex fire. Cleveland (1973) documents flooding and damaging mudslides that occurred after the smaller 1972 fires in the Big Sur watershed. Campgrounds, cabins, resorts, shops, and other businesses are located along the bottom of Big Sur Drainage. It is anticipated that the effects of the moderate burn severity in the watersheds (Pheneger Creek, Juan Higuera Creek, Pfeiffer Redwood Creek) that drain to the developed Big Sur area and State Park areas (Andrew Molera and Pfeiffer Big Sur State Park) will increase and magnify the size and intensity of flooding, debris flows, and mud flows, depending on the severity of the winter and spring rains. Past mitigations have included placement of structures (K-Rails, H-beams with wood lagging, plywood, sand bagging) to direct flow to areas where debris will be minimized from impacting infrastructure. An early warning system tied to prediction of incoming storm events will allow inhabitants to vacate buildings prior to triggering rainfall events.
- **Specific Recommendations:**
  - Follow emergency protective measures listed in Appendix D.
- **General Recommendations:**
  - Develop an early warning system.
  - State Park campgrounds at Andrew Molera and Pfeiffer Big Sur State Parks within the 100-year FEMA flood zone should be closed during storm events.
  - Because the Big Sur River is modeled as a "watch stream", a bulking factor for flow analysis should be considered when designing mitigations. The bulking factor should be used to estimate areas of potential flooding exceeding the FEMA 100-year flood zone. It has been our experience that a bulking factor of 50 percent has been used in other post-fire responses.

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Source : Preliminary Geologic Map of the Point Sur 30' x 60' Quadrangle , California. Rosenberg and Wills, 2016

**Appendix A**
**Geology Map**
**Soberanes Incident**
**CA-BEU-003422**

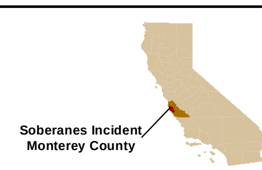
**Soberanes Incident**
**Monterey County**
**Perimeter from 2016/09/12**

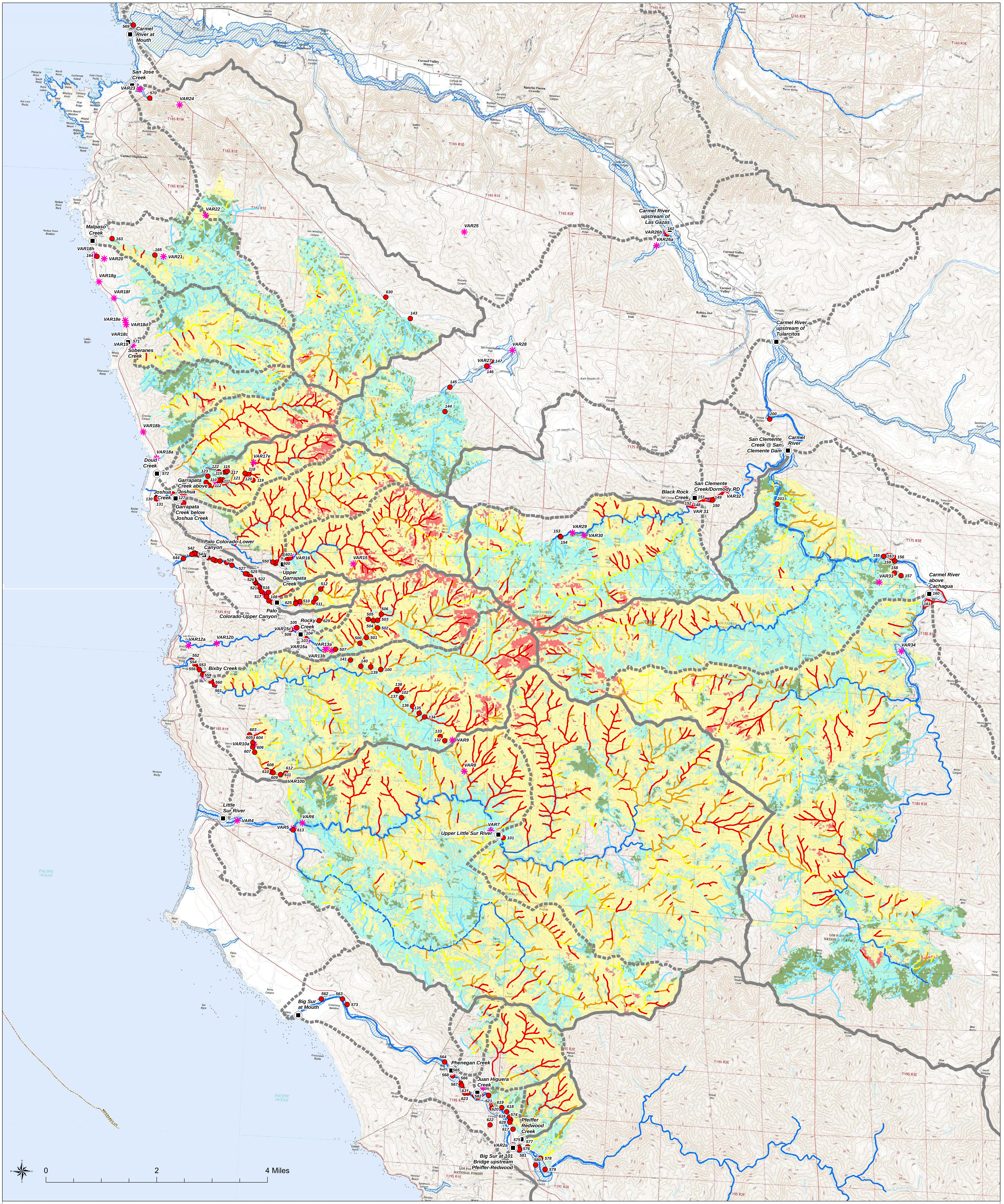
# Geologic Map Units - Soberanes Burn Area

| | |
|---|---|
| af | Artificial fill |
| Qsc | Modern stream channel deposits |
| Qdf, Qydf, Qodf | Debris fan |
| Qls | Landslide deposits |
| Qya, Qoa | Alluvium |
| Tmpm | Miguelito member - Pismo Formation |
| Tmr | Rincon Shale |
| Tts, Tss | Marine Sandstone |
| Tl | Lucia Shale |
| Tj | Junipero Sandstone |
| Tc | Carmelo Formation |
| Ksh | Marine Shale |
| Kss | Marine Sandstone |
| Kgdc, Kqds, Kgh, Kmi, Kqml, Kct | Salinas Complex Granitic Rocks |
| KJf | Greywacke and melange - Franciscan Complex |
| Jsp | Serpentinite - Franciscan Complex |
| pKc, pKg, pKp, pKqf, pKm | Salinas Complex Metamorphic Rocks |
| —— — —....... | Geologic contact: Solid where accurately located, dashed where inferred, dotted where concealed. |
| **——— — —.....** | Fault: Solid where accurately located, dashed where inferred, dotted where concealed. |

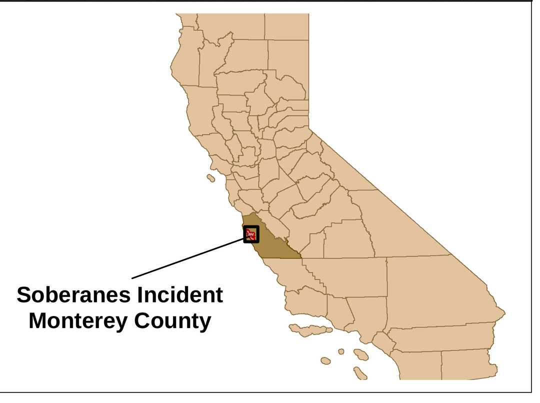
Map units generalized from Preliminary Geologic Map of the Point Sur 30' x 60' Quadrangle, California. Rosenberg and Wills, 2016

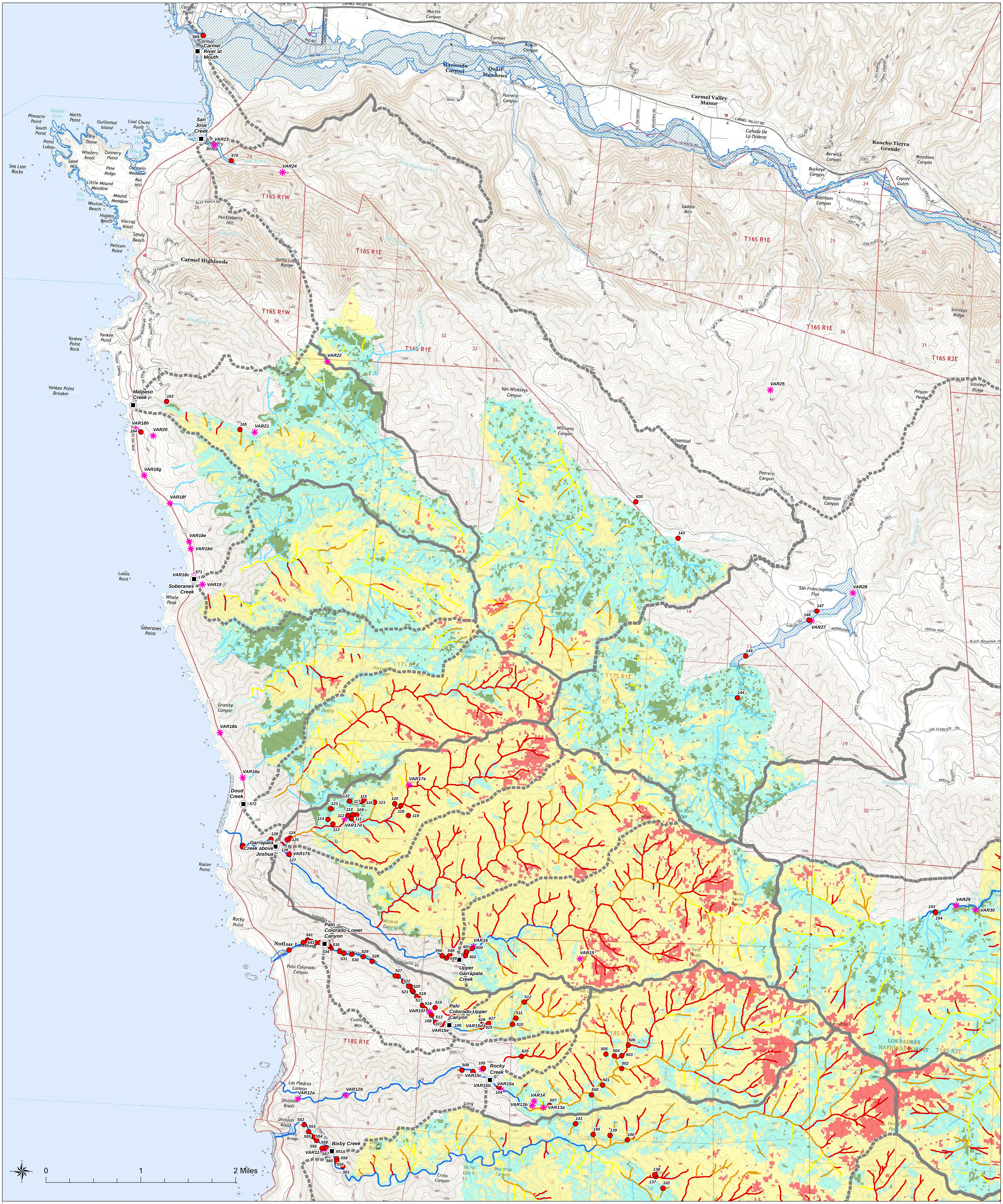
**Geology Map**
**Soberanes Incident**
**CA-BEU-003422**






# Appendix B
# Values at Risk
# Soberanes Incident
# CA-BEU-003422






Pour Points
BAER Identified Values at Risk (VAR)
WERT Values at Risk - Points
WERT Values at Risk - Polygon
Analysis Tier 3
USGS Model Watch Stream
DWR Awareness Floodplains
FEMA Special Flood Hazard Area

Debris Flow Prediction
15 min 28 mmh
0-20%
20-40%
40-60%
60-80%
80-100%

Soil Burn Severity
Unburned/Very Low
Low
Moderate
High

# Appendix B
# Values at Risk - Coastal
# Soberanes Incident
# CA-BEU-003422


Pour Points

BAER Identified Values at Risk (VAR)

WERT Values at Risk - Points

WERT Values at Risk - Polygon

Analysis Tier 3

USGS Model Watch Stream

DWR Awareness Floodplains

FEMA Special Flood Hazard Area

Debris Flow Prediction
15 min 28 mmh

- 0-20%
- 20-40%
- 40-60%
- 60-80%
- 80-100%

Soil Burn Severity

- Unburned/Very Low
- Low
- Moderate
- High

# Appendix B
# Values at Risk - Big Sur
# Soberanes Incident
# CA-BEU-003422


Appendix B
Values at Risk - Carmel
Soberanes Incident
CA-BEU-003422

**Appendix C. Flood and Debris Flow Model Results and Discussion**

**1. Lower Carmel**

1.1. **Mouth**

1.1.1. **Flood Flow Model Results -** The WERT added a pour point at the mouth of Carmel River to better understand the effects of the burn area on the entire Carmel watershed. See table 4 for model results on pour point N1. Pour point N1 analyzes approximately 255 sq. miles of watershed area of which 8.5% had a high or moderate burn severity classification. The pour point was analyzed for a 10 year flood event. The adjusted post fire design flow modifier for pour point 35 was calculated at 1.15. Therefore, flows at the mouth of the Carmel River are estimated to be 1.15 times (15% increase) in pre-fire flow values. Results from the flood model show that a 10 year event at the mouth of the Carmel River is approximately in the magnitude of a 25 year event in pre-fire conditions.

1.1.2. **Debris Flow Model Results-** Because a reltively small area of this watershed was burned (17 percent) very little USGS debris flow modeling results (28mm/hr design storm) appears to impact this water shed. The modeling indicates modeled debris flows in headwater tributaries high in the watershed with probabilities generally ranging from 40 to 100 percent. The USGS debris flow modeling does not shows the Carmel River as a “watch stream”, however a FEMA 100-year flow zone along the Carmel River.

1.2. **Gazas Creek @ Carmel River**

1.2.1. **Flood Flow Model Results -**The WERT added a pour point at the downstream confluence of the Carmel River and Las Gazas Creek to better understand the effect of the burn area on the lower Carmel watershed. See table 4 for model results on pour point N2. Pour point N2 analyzes approximately 211 sq. miles of watershed area of which 10.2% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point N2 was calculated at 1.17. Therefore, flows at the downstream confluence of the Carmel River and Las Gazas Creek are estimated to be 1.17 times (17% increase) pre-fire flow values. Results from the flood model show that a 10 year event at the confluence of the Carmel River and Las Gazas Creek is approximately in the magnitude of a 25 year event in pre-fire conditions.

1.2.2. **Debris Flow Model Results** - Because a relatively small area of this watershed was burned (20 percent) very little USGS debris flow modeling results (28mm/hr design storm) appears to impact this water shed. The modeling indicates modeled debris flows in headwater tributaries high in the watershed with probabilities generally ranging from 40 to 100 percent. The USGS debris flow modeling does not shows the Carmel River as a “watch stream”, however a FEMA 100-year flow zone along the Carmel River.

**2. Upper Carmel**

2.1. **Carmel River @Tularcitos Creek**

2.1.1. **Flood Flow Model Results-**The WERT added a pour point at the downstream confluence of the Carmel River and Turalcitos Creek to better understand the effect of the burn area on the upper Carmel watershed. See table 4 for model results on pour point N3. Pour point N3 analyzes approximately 184.3 sq. miles of watershed area of which 14.2% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point N3 was calculated at 1.18. Therefore, flows at the downstream confluence of the Carmel River and Turalcitos Creek are estimated to be 1.18 times (18% increase) pre-fire flow values. Results from the flood model show that a 10 year event at the confluence of the Carmel River and Turalcitos Creek is approximately in the magnitude of a 25 year event in pre-fire conditions.

2.1.2. **Debris Flow Model Results -**Because a relatively small area of this watershed was burned (20 percent) very little USGS debris flow modeling results (28mm/hr design storm) appears to impact this water shed. The modeling indicates modeled debris flows in headwater tributaries high in the watershed with probabilities generally ranging from 40 to 100 percent. The USGS debris flow modeling does not shows the Carmel River as a "watch stream", however a FEMA 100-year flow zone along the Carmel River.

2.2. **San Clemente @ San Clemente Dam**

2.2.1. **Flood Flow Model Results -**The WERT used an existing BAER pour point 20 (Appendix B) in San Clemente Creek at the San Clemente Dam (decommissioned). See Table 3 for model results on pour point 20. Pour point 20 analyzes approximately 16.7 sq. miles of watershed area of which 22% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 20 was calculated at 1.29. Therefore, flows on the San Clemente Creek at San Clemente Dam (decommissioned) site are estimated to be 1.29 times (29% increase) pre-fire flow values. Results from the flood model show that a 10 year event on the San Clemente Creek at San Clemente Dam (decommissioned) is approximately in the magnitude of a 25 year event in pre-fire conditions

2.2.2. **Debris Flow Model Results-**Only a small portion of the headwaters of this drainage area burned. USGS debris flow modeling results (28mm/hr design storm) shows a 0 to 20 percent probability of debris flows for headwater tributaries that drain into Upper San Clemente Creek. These tributaries are more than 4 miles upstream from the confluence of San Clemente Creek and Black Rock Creek.

2.3. **Carmel River @ San Clemente Dam**

2.3.1. **Flood Flow Model Results -** The WERT used an existing BAER pour point 19 (Appendix B) in Carmel River at the San Clemente Dam (decommissioned). See table 3 for model results on pour point 19. Pour point 19 analyzes approximately 125.5 sq. miles of watershed area of which 17.5% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 19 was calculated at 1.19. Therefore, flows on the Carmel River at San Clemente Dam (decommissioned) site are estimated to be 1.19 times (19% increase) pre-fire flow values. Results from the flood model show that a 10 year event on the Carmel River at San Clemente Dam (decommissioned) is approximately in the magnitude of a 25 year event in pre-fire conditions.

**2.3.2. Debris Flow Model Results** The fire did not burn the Lower San Clemente watershed below the confluence of Upper San Clemente Creek and Black Rock Creek. The USGS debris flow modeling results (28mm/hr design storm) do not identify additional debris flow segments downstream of the confluence.

2.4. **San Clemente Creek @ Black Rock**

2.4.1. **Flood Flow Model Results-** The WERT used an existing BAER pour point 27 (Appendix B) on San Clemente Creek at Dormody Road. See table 3 for model results on pour point 27. Pour point 27 analyzes approximately 5.8 sq. miles of watershed area of which 1.2% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 27 was calculated at 1.03. Therefore, flows on the San Clemente Creek at Dormody Road are estimated to be 1.03 times (3% increase) pre-fire flow values. Results from the flood model show that a 10 year event on the San Clemente Creek at Dormody Road is comparable in magnitude of a 10 year event in pre-fire conditions.

2.4.2. **Debris Flow Model Results** Only a small portion of the headwaters of this drainage area burned. USGS debris flow modeling results (28mm/hr design storm) shows a 0 to 20 percent probability of debris flows for headwater tributaries that drain into Upper San Clemente Creek. These tributaries are more than 4 miles upstream from the confluence of San Clemente Creek and Black Rock Creek.

**2.5 Black Rock @ SF Black Rock Creek**

**2.5.1 Flood Flow Model Results -** The WERT used an existing BAER pour point 28 (Appendix B) at the confluence of Black Rock Creek and South Fork Black Rock Creek. See Table 3 for model results on pour point 28. Pour point 28 analyzes approximately 8.2 sq. miles of watershed area of which 44.1% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 28 was calculated at 1.54. Therefore, flows at the confluence of Black Rock Creek and South Fork Black Rock Creek are estimated to be 1.54 times (54% increase) pre-fire flow values. Results from the flood model show that a 10 year event at the confluence of Black Rock Creek and South Fork Black Rock Creek is approximately in the magnitude of a 25 to 50 year event in pre-fire conditions.

**2.5.2 Debris Flow Model Results -** USGS debris flow modeling results (28mm/hr design storm) generally shows a 40 to 100 percent probability of debris flows for headwater tributaries that drain into Black Rock Creek and South Fork Black Rock Creek. The model results generally show a 0 to 60 percent probability for north facing slopes and 60 to 100 percent probability of debris flows for south facing slopes along the main stems of both Black Rock Creek and South Fork Black Rock Creek. The results also indicate that the main stem of Black Rock Creek is a “watch stream”. It should be understood that the slopes in this area may be impacted directly by debris flows, while the main stem of Black Rock Creek may be impacted by the combined effects of debris flow and floods, including increased sediment and debris generated from upstream tributaries.

**2.6 Carmel River @ Cachuaga**

**2.6.1 Flood Flow Model Results** The WERT used an existing BAER pour point 23 (Appendix B) at the confluence of Carmel Creek and Cachuaga Creek. See Table 4 for model results on pour point 23. Pour point 23 analyzes approximately 108.9 sq. miles of watershed area of which

10.7% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 23 was calculated at 1.16. Therefore, flows at the confluence of Carmel Creek and Cachuaga Creek are estimated to be 1.16 times (16% increase) pre-fire flow values. Results from the flood model show that a 10 year event at the confluence of Carmel Creek and Cachuaga Creek is approximately in the magnitude of a 25 year event in pre-fire conditions.

**2.6.2 Debris Flow Model Results -**USGS debris flow modeling results (28mm/hr design storm) shows the majority of modeled debris flows in headwater tributaries (Ventana Mesa Creek and Rattlesnake Creek) that drain into the Carmel River generally ranging with probabilities between 60 to 100 percent. These drainages drain to the portion of the Carmel River that drains into the Los Padres Dam. The USGS debris flow modeling shows the lower Ventana Mesa Creek and Rattlesnake Creek as “watch streams”. The USGS stream watch segments shown in the model results indicate the presence of drainages within and below the burn area that can be impacted by the combined affects of debris flows and floods generated from tributaries. These are areas where a combination of runoff hazards may be present, and where flood hazards analyses may be need to consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris.

## 3 Upper Coastal Watersheds

### 3.1 San Jose Creek

3.1.1 **Flood Flow Model Results -** The WERT used an existing BAER pour point 21 (Appendix B) on the mouth of San Jose Creek at Carmel River State Beach. See Table 3 for model results on pour point 21. Pour point 21 analyzes approximately 14.1 sq. miles of watershed area of which 16.1% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 21 was calculated at 1.19. Therefore, flows at San Jose Creek at Carmel River State Beach are estimated to be 1.19 times (19% increase) pre-fire flow values. Results from the flood model show that a 10 year event at San Jose Creek at Carmel River State Beach is approximately in the magnitude of a 25 year event in pre-fire conditions.

3.1.2 **Debris Flow Model Results -** USGS debris flow modeling results (28mm/hr design storm) generally shows a 20 to 100 percent probability of debris flows for the headwater tributaries that drain north facing slopes from the ridge line of White Rock Ridge. These drainages drain towards two residential homes, MP 143 and 630, which are located on debris/alluvial fans adjacent to San Jose Creek. Downstream, San Jose Creek drains towards residential structures located within Carmel River State Beach, MP 570. It should be understood that although Carmel River State Beach is not located within an area of mapped debris flow hazards, it could be impacted directly by flood flows that travel through the area via San Jose Creek. The USGS debris flow modeling does not show San Jose Creek as a “watch stream”.

### 3.2 Malpaso, Soberanes and Doud Creeks

#### 3.2.1 Flood Flow Model Results

- **Soberanes Creek**: Pour point 17 analyzes approximately 3 sq. miles of watershed area of which 50.2% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 17 was calculated at 1.55. Therefore, flows at Soberanes

Creek at Soberanes State Park are estimated to be 1.55 times (55% increase) pre-fire flow values. Results from the flood model show that a 10 year event at Soberanes Creek at Soberanes State Park is approximately in the magnitude of a 25 to 50 year event in pre-fire conditions. See Table 3 for model results on pour point 17.

- **Doud Creek:** Pour point 12 analyzes approximately 2.7 sq. miles of watershed area of which 71.3% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 12 was calculated at 1.75. Therefore, flows at Daud Creek near Highway 1 are estimated to be 1.75 times (75% increase) pre-fire flow values. Results from the flood model show that a 10 year event at Daud Creek near Highway 1 is approximately in the magnitude of a 25 to 50 year event in pre-fire conditions. See Table 3 for model results on pour point 12.
- **MalPaso -** Pour point 18 analyzes approximately 3.3 sq. miles of watershed area of which 28.2% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 18 was calculated at 1.39. Therefore, flows in Malpaso Creek Near Highway 1 are estimated to be 1.39 times (39% increase) pre-fire flow values. Results from the flood model show that a 10 year event in Malpaso Creek is approximately in the magnitude of a 25 year event in pre-fire conditions. See Table 3 for model results on pour point 18.

**3.2.2 Debris Flow Model Results -**The principal tributaries that the USGS modeling shows as probable debris flow locations are Malpaso Creek, Soberanes Creek, and Doud Creek (listed from north to south). The USGS debris flow modeling results (28mm/hr design storm) generally shows a 60 to 100 percent probability of debris flows for the Malpaso and Doud Creek and a 40 to 100 percent probability for Soberanes Creek. These drainages are not shown as “watch streams”. However, it should be understood that infrastructure along these creeks could be impacted by increased flows (flooding) containing and bulked by sediment and debris

## 3. Middle Coastal Watersheds

### 3.1. Joshua Creek

**3.1.1. Flood Flow Model Results-** The WERT added a pour point on Joshua Creek upstream of the Garrapata Creek confluence. Pour point N4 analyzes approximately 2.1 sq. miles of watershed area of which 77.9% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point N4 was calculated at 1.82. Therefore, flows on Joshua Creek upstream of the Garrapata Creek confluence are estimated to be 1.82 times (82% increase) pre-fire flow values. Results from the flood model show that a 10 year event on Joshua Creek upstream of the Garrapata Creek confluence is approximately in the magnitude of a 50 year event in pre-fire conditions. See Table 3 for model results on pour point N4.

**3.1.2. Debris Flow Model Results** USGS debris flow modeling results (28mm/hr design storm) generally shows a 60 to 100 percent probability of debris flows for headwater tributaries. These drainages drain to the portion of Joshua Creek that flows towards infrastructure including culverts, residential access bridges, a residence and several water tanks. The USGS debris flow modeling does not show Joshua Creek as a “watch stream”. It should be understood that the existing homes and infrastructure could be impacted directly by debris flows or indirectly via sediment and debris that travels through the area via Joshua Creek.

### 3.2 Garrapata Creek-

**3.2.1 Flood Flow Model Results Lower Garrapata -**The WERT added a pour point on Garrapata Creek upstream of the Joshua Creek confluence. Pour point N5 analyzes approximately 8.4 sq. miles of watershed area of which 78.4% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point N4 was calculated at 1.81. Therefore, flows on Garrapata Creek upstream of the Joshua Creek confluence are estimated to be 1.81 times (81% increase) pre-fire flow values. Results from the flood model show that a 10 year event on Garrapata Creek upstream of the Joshua Creek confluence is approximately in the magnitude of a 50 to 100 year event in pre-fire conditions. See table 4 for model results on pour point N5.

**3.2.2 Flood Flow Model Results Mouth of Garrapata** The WERT used an existing BAER pour point #11. See table 4 for model results on pour point 11. Pour point 11 analyzes approximately 10.5 sq. miles of watershed area of which 78.2% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point N8 was calculated at 1.80. Therefore, flows at the mouth of Garrapata Creek are estimated to be 1.80 times (80% increase) pre-fire flow values. Results from the flood model show that a 10 year event on the mouth of Garrapata Creek is approximately in the magnitude of a 50 to 100 year event in pre-fire conditions.

**3.2.3 Debris Flow Model Results -** USGS debris flow modeling results (28mm/hr design storm) do not show a probability of debris flows for Lower Garrapata Creek. However, this drainage does drain an area of Upper Garrapata Creek and Joshua Creek that have a 60 to 100 percent probability of debris flows. In addition, Garrapata Creek, including Lower Garrapata Creek is shown as a “watch stream”. Lower Garrapata Creek drains towards several residences and associated infrastructure, including water wells (VARS 127-131). It should be understood that the residences and infrastructure could be impacted directly by debris flows or indirectly via sediment and debris that travels through the area via Joshua and Upper Garrapata Creeks.

### 3.3 Garrapatos Road (Upper Garrapata Creek)

**3.3.1 Flood Flow Model Results -** The WERT used an existing BAER pour point 10 on upper Garrapata Creek in the Garapatos Road Community. Pour point 10 analyzes approximately 4.3 sq. miles of watershed area of which 88.8% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 10 was calculated at 1.90. Therefore, flows at Upper Garrapata Creek in the Garapatos Community are estimated to be 1.90 times (90% increase) pre-fire flow values. Results from the flood model show that a 10 year event in upper Garrapata Creek is approximately in the magnitude of a 100 year event in pre-fire conditions. See Table 3 for model results on pour point 10.

**3.3.2 Debris Flow Model Results -** USGS debris flow modeling results (28mm/hr design storm) generally shows a 60 to 100 percent probability of debris flows for tributaries that drain into Garrapata Creek and along the upper segment of Garrapata Creek. The results also indicate that the main stem of Garrapata Creek is a “watch stream”. It should be understood that slopes in the Upper Garrapata Creek watershed and Garrapata Creek may be impacted directly by debris flows, while the lower reach of Garrapata Creek may be impacted by the combined effects of debris flow and floods, including increased sediment and debris generated from upstream tributaries.

### 3.4 Lower Palo Colorado

**3.4.1 Flood Flow Model Results -** See Table 3 for model results on pour point 8. Pour point 8 analyzes approximately 1.9 sq. miles of watershed area of which 33.2% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 8 was calculated at 1.35. Therefore, flows at lower Palo Colorado Canyon are estimated to be 1.35 times (35% increase) pre-fire flow values. Results from the flood model show that a 10 year event in lower Palo Colorado Canyon is approximately in the magnitude of a 25 year event in pre-fire conditions. See Table 3 for model results on pour point 8.

**3.4.2 Debris Flow Model Results -** In addition to the debris flow modeling for Upper Palo Colorado (discussed above), USGS debris flow modeling results (28mm/hr design storm) shows a 60 to 100 percent probability of debris flows for two tributaries that drain south facing slopes within the burn area. The results also indicate that the main stem of Palo Colorado is a "watch stream". It should be understood that the south facing slopes in this area may be impacted directly by debris flows, while Palo Colorado may be impacted by the combined effects of debris flow and floods, including increased sediment and debris generated from upstream tributaries.

### 3.5 Upper Palo Colorado-

**3.5.1 Flood Flow Model Results-**The WERT used an existing BAER pour point 9 (Appendix B) on upper Palo Colorado at the upper road crossing. Pour point 9 analyzes approximately 0.7 sq. miles of watershed area of which 78.2% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 9 was calculated at 1.81. Therefore, flows at upper Palo Colorado are estimated to be 1.81 times (81% increase) pre-fire flow values. Results from the flood model show that a 10 year event in upper Palo Colorado is approximately in the magnitude of a 100 year event in pre-fire conditions. See Table 3 for model results on pour point 9.

**3.5.2 Debris Flow Model Results** USGS debris flow modeling results (28mm/hr design storm) generally shows a 60 to 100 percent probability of debris flows for tributaries that drain into Palo Colorado, and a 60 to 80 percent probability of debris flow along Palo Colorado. The USGS debris flow modeling shows the lower segment of Palo Colorado in this area as a "watch stream". It should be understood that the slopes in this area and Palo Colorado may be impacted directly by debris flows. Palo Colorado may also be impacted by the combined effects of debris flow and floods, including increased sediment and debris generated from upstream tributaries.

### 3.6 Rocky Creek

**3.6.1 Flood Flow Model Results -** The WERT used an existing BAER pour point 7 (Appendix B) on Rocky Creek near the Hoist community. Pour point 7 analyzes approximately 3.5 sq. miles of watershed area of which 77.3% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 7 was calculated at 1.81. Therefore, flows in Rocky Creek near the Hoist community are estimated to be 1.81 times (81% increase) pre-fire flow values. Results from the flood model show that a 10 year event in Rocky Creek is approximately in the magnitude of a 100 year event in pre-fire conditions. See Table 3 for model results on pour point 7.

**3.6.2 Debris Flow Model Results** USGS debris flow modeling results (28mm/hr design storm) generally shows a 60 to 100 percent probability of debris flows for tributaries that drain into Rocky Creek, and a 60 to 80 percent probability of debris flow along the upper main stem of Rocky Creek. The results also indicate that the lower main stem of Rocky Creek is a "watch stream". It should be understood that slopes in the upper reaches of Rocky Creek may be impacted directly by debris flows, while the lower reaches may be impacted by the combined effects of debris flow and floods, including increased sediment and debris generated from upstream tributaries.

### 3.7 Bixby Creek

**3.7.1 Flood Flow Model Results -**The WERT used an existing BAER pour point #30 (Appendix B) on Bixby Creek at Coast Road near the lower flood plain community. Pour point 30 analyzes approximately 11 sq. miles of watershed area of which 54.4% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 30 was calculated at 1.61. Therefore, flows in lower Bixby Creek are estimated to be 1.61 times (61% increase) pre-fire flow values. Results from the flood model show that a 10 year event in the lower Bixby Creek area is approximately in the magnitude of a 25 to 50 year event in pre-fire conditions. See Table 4 for model results on pour point 30.

**3.7.2 Debris Flow Model Results**

- Lower Bixby Creek. USGS debris flow modeling results (28mm/hr design storm) generally shows a 60 to 100 percent probability of debris flows for headwater tributaries that drain south facing slopes from the ridge line of Long Ridge and the north facing slopes of Mescal and Skinner Ridges. These drainages drain to the portion of Bixby Creek that flows towards an existing bridge (where the Coast road crosses Bixby Creek) and a group of residential homes, VARs 554 through 561. The USGS debris flow modeling shows Bixby Creek as a "watch stream". It should be understood that the existing homes and infrastructure could be impacted directly by debris flows or indirectly via sediment and debris that travels through the area via Bixby Creek.

- Coast Road. USGS debris flow modeling results (28mm/hr design storm) generally shows a 40 to 100 percent probability of debris flows for headwater tributaries that drain the south facing slopes of Mescal Ridge/Bonifacio Hill. This drainage drains to a portion of Sierra Creek that flows through multiple culverts along the Coast Road and adjacent to one existing residence, VARs 603 through 612. Sierra Creek does converge with Bixby Creek approximately ¾ of a mile downstream of VAR 603, however it is not shown as a "watch stream". It should be understood that the infrastructure and residence could be impacted directly by debris flows or indirectly via sediment and debris that travels through the area via Sierra Creek.
- Mill Creek and Turner Creek USGS debris flow modeling results (28mm/hr design storm) generally shows a 60 to 100 percent probability of debris flows for tributaries that drain south facing slopes in this area and a 0 to 60 percent probability for tributaries that drain north facing slopes in this area. The results show a 60 to 80 percent probability of debris flow along the main stem of Turner Creek, and a 60 to

100 percent probability of debris flow along the main stem of Mill Creek. It should be understood that slopes in the Mill Creek and Turner Creek watershed may be impacted directly by debris flows.

# 4. Little Sur

## 4.1. Upper Little Sur/ Boy Scout

**4.1.1. Flood Flow Model Results -**The WERT used an existing BAER pour point 25 (Appendix B) in the middle Little Sur River area near the Pico Blanco Boy Scouts Camp. Pour point 25 analyzes approximately 18.3 sq. miles of watershed area of which 70.2% had a high or moderate burn severity classification. The pour point was analyzed for a 10 year flood event. The adjusted post fire design flow modifier for pour point 25 was calculated at 1.74. Therefore, flows near the Boy Scout Camp at pour point 25, middle Little Sur, are estimated to be 1.74 times (74% increase) pre-fire flow values. Results from the flood model show that a 10 year event in the middle Little Sur River area is approximately in the magnitude of a 50 to 100 year event in pre-fire conditions. See Table 3 for model results on pour point 25.

**4.1.2. Debris Flow Model Results** - USGS debris flow modeling results (28mm/hr design storm) generally shows a 60 to 100 percent probability of debris flows for headwater tributaries that drain south facing slopes from the ridge line from Devils Peak/Skinner Ridge to Uncle Sam Mountain. The USGS debris flow modeling of north facing slopes in the watershed shows a lower probability of debris flows (generally ranging from 20 to 60 percent) compared to the south facing slopes. These drainages drain to the portion of the Little Sur River that drains to the Pico Blanco Boy Scout Camp, and the USGS debris flow modeling shows Little Sur River as a "watch stream". It should be understood that the campground could be impacted by directly by debris flows or indirectly via sediment and debris that travels through the campground via Little Sur River.

## 4.2 Lower Little Sur

**4.2.1 Flood Flow Model Results -**. Pour point 4 analyzes the entire Little Sur watershed area. Pour point 4 analyzes approximately 40 sq. miles of watershed area of which 59.6% had a high or moderate burn severity classification. The pour point was analyzed for a 10 year flood event. The adjusted post fire design flow modifier for pour point 4 was calculated at 1.65. Therefore, flows near the mouth of Little Sur River at Highway 1 are estimated to be 1.65 times (65% increase) of pre-fire flow values. Results from the flood model show that a 10 year event at the mouth of Little Sur River is approximately in the magnitude of a 50 year event in pre-fire conditions. See Table 3 for model results on pour point 4.

**4.2.2 Debris Flow Model Results -** USGS debris flow modeling results (28mm/hr design storm) shows the majority of modeled debris flows in headwater tributaries that drain south facing slopes from the ridge line that descends from Bixby Mountain. The debris flow modeling indicates probabilities generally ranging from 60 to 100 percent. These drainages drain to the portion of the Little Sur River which outlets to the Pacific Ocean. The USGS debris flow modeling shows the lower Little Sur River as a "watch stream". The USGS stream watch segments shown in the model results indicate the presence of drainages within and below the burn area that can be impacted by the combined effects of debris flows and floods generated from tributaries. These are areas where a combination of runoff hazards may be present, and where flood hazards analyses may be need to consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris

# 5. Big Sur River

## 5.1. Flood Flow Model Results-

**5.1.1. Upper Big Sur -** Pour point N6 analyzes approximately 49.1 sq. miles of watershed area of which 51.9% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point N6 was calculated at 1.57. Therefore, flows on Big Sur River at the Highway 1 bridge are estimated to be 1.57 times (57% increase) pre-fire flow values. Results from the flood model show that a 10 year event on Big Sur River at Highway 1 Bridge is approximately in the magnitude of a 50 year event in pre-fire conditions. See Table 3 for model results on pour point N6.

**5.1.2. Pfeiffer Creek -** Pour point 3 analyzes approximately 0.9 sq. miles of watershed area of which 65.9% had a high or moderate burn severity classification. The pour point was analyzed for a 10 year flood event. The adjusted post fire design flow modifier for pour point 3 was calculated at 1.73. Therefore, flows on Pfeiffer Creek upstream of Big Sur confluence are estimated to be 1.73 times (73% increase) pre-fire flow values. Results from the flood model show that a 10 year event on Pfeiffer Creek is approximately in the magnitude of a 50 year event in pre-fire conditions. See Table 3 for model results on pour point 3.

**5.1.3. Juan Higuerra Creek-** Pour point 2 analyzes approximately 1.8 sq. miles of watershed area of which 74.2% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 2 was calculated at 1.77. Therefore, flows in Juan Hiquera Creek Near Highway 1 are estimated to be 1.77 times (77% increase) pre-fire flow values. Results from the flood model show that a 10 year event in Juan Hiquera Creek is approximately in the magnitude of a 50 year event in pre-fire conditions. See Table 3 for model results on pour point 2.

**5.1.4. Pheneger Creek-** Pour point 1 analyzes approximately 0.8 sq. miles of watershed area of which 23.2% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point 1 was calculated at 1.25. Therefore, flows in Pheneger Creek near Highway 1 are estimated to be 1.25 times (25% increase) pre-fire flow values. Results from the flood model show that a 10 year event in Pheneger Creek is approximately in the magnitude of a 25 year event in pre-fire conditions. See Table 3 for model results on pour point 1.

**5.1.5. Molera State Park-** Pour point N7 analyzes approximately 58.7 sq. miles of watershed area of which 47.2% had a high or moderate burn severity classification. The adjusted post fire design flow modifier for pour point N7 was calculated at 1.53. Therefore, flows at the mouth of Big Sur River are estimated to be 1.53 times (53% increase) pre-fire flow values. Results from the flood model show that a 10 year event on the mouth of the Big Sur River is approximately in the magnitude of a 25 to 50 year event in pre-fire conditions. See Table 3 for model results on pour point N7.

## 5.2 Debris Flow Model Results

The principal tributaries that the USGS modeling shows as probable debris flow locations are Pheneger Creek, Juan Higuera Creek, and Pfeiffer Redwood Creek, all of which are perched above the resort and State Park communities of Big Sur. The USGS debris flow modeling results (28mm/hr design storm) generally shows a 60 to 100 percent probability of debris flows for the Pheneger Creek, Juan Higuera Creek, and Pfeiffer Redwood Creek drainages. These drainages drain to the Big Sur River that the USGS debris flow modeling shows as a “watch stream”. It should be understood that infrastructure along the “watch stream”, in this case the Big Sur River, could be impacted by increased flows (flooding) containing and bulked by sediment and debris.

Appendix C. Flood and Debris Flow Model Results

| | Watershed Acres | | | Burn Severity | | | | Post Fire 10 year Discharge (CFS) | | | | | Pre Fire Discharge | | | | Times Increase (10yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Watershed | Watershed Acres | Average Precip | Watershed Miles$^2$ | Miles$^2$ High | Miles$^2$ Moderate | Miles$^2$ Low | Miles$^2$ Unburned | Discharge High | Discharge Moderate | Discharge Low | Discharge Unburned | Total Discharge | Q10 | Q25 | Q50 | Q100 | x increase flow |
| 1. Pheneger Creek | 522 | 36 | 0.82 | 0.00 | 0.19 | 0.07 | 0.56 | 0.4 | 68.4 | 14.8 | 102.9 | 186.6 | 149.6 | 219.8 | 277.8 | 328.1 | 1.25 |
| 2. Juan Higuera Creek | 1,165 | 38 | 1.82 | 0.00 | 1.35 | 0.21 | 0.26 | 0.2 | 470.1 | 45.4 | 45.5 | 561.3 | 317.6 | 458.7 | 573.8 | 673.2 | 1.77 |
| 3. Pfeiffer Redwood Creek | 545 | 37 | 0.85 | 0.00 | 0.56 | 0.24 | 0.05 | 0.6 | 208.5 | 55.1 | 8.5 | 272.7 | 157.7 | 231.1 | 291.4 | 343.8 | 1.73 |
| 4. Little Sur River | 25,607 | 40 | 40.01 | 0.12 | 23.74 | 10.13 | 6.02 | 29.2 | 5716.0 | 1462.0 | 752.4 | 7959.6 | 4817.0 | 6735.0 | 8273.4 | 9610.8 | 1.65 |
| 7. Rocky Creek | 2,225 | 45 | 3.48 | 0.39 | 2.30 | 0.61 | 0.18 | 160.4 | 952.8 | 149.4 | 38.3 | 1300.9 | 720.7 | 985.3 | 1193.2 | 1364.5 | 1.81 |
| 8. Palo Colorado Lower Canyon | 1,195 | 28 | 1.87 | 0.01 | 0.61 | 0.09 | 1.15 | 2.7 | 129.9 | 13.1 | 123.2 | 268.8 | 198.8 | 315.6 | 417.6 | 513.0 | 1.35 |
| 9. Palo Colorado Upper RD crossing | 442 | 36 | 0.69 | 0.01 | 0.53 | 0.09 | 0.06 | 4.6 | 194.0 | 19.4 | 11.5 | 229.5 | 126.5 | 187.0 | 237.0 | 280.7 | 1.81 |
| 10. Garrapatos RD | 2,734 | 44 | 4.27 | 0.48 | 3.31 | 0.39 | 0.09 | 187.5 | 1301.9 | 90.6 | 18.5 | 1598.5 | 839.3 | 1151.4 | 1397.2 | 1601.1 | 1.90 |
| 11. Garrapata Creek at Trout Farm | 6,696 | 39 | 10.46 | 0.76 | 7.42 | 0.96 | 1.32 | 209.8 | 2061.3 | 161.6 | 187.7 | 2620.4 | 1452.3 | 2066.9 | 2564.6 | 2997.2 | 1.80 |
| 12. Doud Creek | 1,740 | 35 | 2.72 | 0.16 | 1.78 | 0.42 | 0.35 | 47.5 | 517.4 | 76.4 | 51.7 | 693.1 | 395.4 | 583.6 | 739.6 | 877.6 | 1.75 |
| 17. Soberanes Creek | 1,929 | 30 | 3.01 | 0.02 | 1.49 | 1.03 | 0.34 | 4.4 | 331.9 | 146.9 | 38.5 | 521.6 | 336.4 | 520.7 | 678.8 | 824.4 | 1.55 |
| 18. Malpaso Creek | 2,109 | 28 | 3.30 | 0.01 | 0.92 | 1.18 | 1.19 | 2.3 | 182.0 | 150.5 | 119.0 | 453.8 | 326.5 | 515.5 | 680.1 | 834.2 | 1.39 |
| 19. Carmel River | 80,320 | 37 | 125.50 | 0.52 | 16.47 | 11.20 | 97.31 | 90.5 | 2850.0 | 1178.9 | 8834.8 | 12954.1 | 10856.9 | 15567.3 | 19419.7 | 22888.7 | 1.19 |
| 20. San Clemente Creek/San Clemente Dam | 10,666 | 33 | 16.67 | 0.23 | 3.45 | 3.56 | 9.43 | 45.3 | 681.1 | 438.5 | 957.0 | 2121.9 | 1645.0 | 2461.3 | 3146.7 | 3771.7 | 1.29 |
| 21. San Jose Creek | 9,041 | 27 | 14.13 | 0.05 | 1.78 | 2.12 | 10.17 | 7.0 | 256.2 | 198.4 | 750.6 | 1212.1 | 1015.1 | 1623.7 | 2159.7 | 2673.4 | 1.19 |
| 23. Carmel @ Cachuaga | 69,682 | 39 | 108.88 | 0.27 | 11.43 | 7.37 | 89.81 | 52.9 | 2224.6 | 863.8 | 9160.7 | 12302.1 | 10597.1 | 14924.7 | 18419.9 | 21515.4 | 1.16 |
| 25. Middle Little Sur | 11,685 | 47 | 18.26 | 0.05 | 12.78 | 3.38 | 2.05 | 15.8 | 4413.3 | 683.0 | 365.0 | 5477.1 | 3153.1 | 4222.5 | 5054.3 | 5740.4 | 1.74 |
| 27. San Clemente Creek/Dormody RD | 3,697 | 31 | 5.78 | 0.00 | 0.07 | 0.11 | 5.60 | 0.1 | 14.1 | 14.5 | 602.5 | 631.3 | 610.6 | 934.4 | 1210.2 | 1463.5 | 1.03 |
| 28. Black Rock Creek | 5,233 | 37 | 8.18 | 0.23 | 3.38 | 3.45 | 1.12 | 62.2 | 917.7 | 570.9 | 155.3 | 1706.1 | 1109.7 | 1599.4 | 1999.3 | 2349.9 | 1.54 |
| 30. Bixby Creek on Coast Road | 7,057 | 36 | 11.03 | 0.49 | 5.51 | 3.13 | 1.90 | 119.8 | 1357.0 | 472.7 | 239.9 | 2189.3 | 1357.9 | 1974.1 | 2480.7 | 2929.8 | 1.61 |
| N3 Carmel River Upstream of Tularcitos Creek | 117,952 | 31 | 184.30 | 0.75 | 19.88 | 18.06 | 145.60 | 92.1 | 2436.3 | 1390.3 | 9397.7 | 13316.4 | 11290.8 | 17080.4 | 21999.2 | 26635.1 | 1.18 |
| N2 Carmel River Upstream of Las Gazas Creek | 135,034 | 30 | 210.99 | 0.77 | 20.79 | 20.40 | 168.48 | 88.6 | 2401.3 | 1486.7 | 10266.5 | 14243.0 | 12186.9 | 18561.7 | 24004.9 | 29167.5 | 1.17 |
| N1 Carmel River Watershed | 163,046 | 29 | 254.76 | 0.77 | 20.79 | 20.40 | 212.81 | 78.2 | 2118.7 | 1325.9 | 11463.2 | 14986.0 | 12983.4 | 20129.6 | 26310.8 | 32259.6 | 1.15 |
| N4 Joshua Creek | 1329 | 35 | 2.08 | 0.16 | 1.46 | 0.33 | 0.12 | 46.7 | 435.2 | 61.8 | 18.6 | 562.3 | 309.2 | 458.5 | 582.5 | 692.3 | 1.82 |
| N5 Lower Garrapata | 5,371 | 40 | 8.39 | 0.60 | 5.98 | 0.79 | 1.02 | 180.3 | 1786.0 | 142.6 | 156.1 | 2265.0 | 1254.1 | 1772.8 | 2190.7 | 2550.6 | 1.81 |
| N6 Upper Big Sur River @ 101 Bridge | 31,404 | 45 | 49.07 | 2.78 | 22.69 | 12.13 | 11.46 | 785.7 | 6408.9 | 2010.3 | 1683.2 | 10888.0 | 6929.6 | 9330.9 | 11209.8 | 12790.2 | 1.57 |
| N7 Big Sur River @ Mouth | 37,561 | 43 | 58.69 | 2.72 | 25.01 | 12.89 | 18.07 | 675.1 | 6202.9 | 1896.7 | 2334.3 | 11109.0 | 7279.2 | 9989.5 | 12138.0 | 13983.0 | 1.53 |

# Appendix D: Values at Risk Matrix

This table and general recommendations are part of a larger document and therefore should be used in conjunction with that document in order to implement the recommendations provided

| Community | Site Number | Address | Field Observation | Hazard Category | Feature | Feature Category | Hazard to Life | Hazard to Property | In FEMA/DWR 100 yr floodplain | Preliminary Emergency Protective Measures | Subwatershed (Tier 2) | Pour Point | Latitude (Decimal Degrees) | Longitude (Decimal Degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Andrew Molera State Park | 562 | Off Highway 1 | Campsites in floodway | debris flow / flood | Camp | Recreation | high | low | yes | Close lower two campsites and early warning system | Lower Big Sur | N7 | 36.28665N | 121.85073W |
| Andrew Molera State Park | 563 | Off Highway 1 | Campsites in floodway | debris flow / flood | Camp | Recreation | high | low | yes | early warning system | Lower Big Sur | N7 | 36.28691N | 121.84385W |
| Andrew Molera State Park | 573 | Andrew Molera State Park | Flooding of state park residential structures, earthen berm breached | flood | Park facilities and buildings | State Park | low | moderate | yes | Install muscle wall across breach in berm | Lower Big Sur | N7 | 36.28556N | 121.84229W |
| Big Sur Resorts | 564 | Brewer Bridge - Clear Ridge Road | Bridge crossing to residential neighborhood | flood | Bridge | drainage structure | low | low | yes | storm patrol | Lower Big Sur | N7 | 36.27177N | 121.80987W |
| Big Sur Resorts | 565 | Big Sur River Inn off Highway 1 | Shops and resorts in floodway. Also two residences on west side of Big Sur River | flood | Infrastructure | multiple | high | high | yes | early warning system | Lower Big Sur | N7 | 36.26978N | 121.80842W |
| Big Sur Resorts | 566 | Big Sur Campground off Highway 1 | Big Sur campground, especially sites along river | flood | Infrastructure | recreational | high | high | yes | no camping during storm events | Lower Big Sur | N7 | 36.26646N | 121.80438W |
| Big Sur Resorts | 567 | Riverside campground off Highway 1 | Plugging of Concrete low water concrete crossing. Campsites near river. | flood | Infrastructure | recreational | high | high | yes | no camping during storm events, storm patrol | Lower Big Sur | N7 | 36.26592N | 121.80403W |
| Big Sur Resorts | 568 | Santa Lucia Camp off Highway 1 | Campground near river | flood | Infrastructure | recreational | high | low | no | no camping during storm events | Lower Big Sur | N7 | 36.26829N | 121.80706W |
| Big Sur Resorts | 614 | Highway 1 at Pheneger Creek | 6' culvert plug and diversion to Big Sur Village | debris flow / flood | Culvert | drainage structure | high | high | no | storm patrol | Lower Big Sur | N7 | 36.26949N | 121.80720W |
| Big Sur Resorts | 615 | road at Juan Higara Creek | 6' culvert plug and diversion to Big Sur grange within FEMA zone | debris flow / flood | Culvert | drainage structure | moderate | high | yes | storm patrol | Lower Big Sur | N7 | 36.26334N | 121.79956W |
| Big Sur Resorts | 616 | Highway 1 | Plugging of 18" culvert | debris flow | Culvert at Highway 1 | drainage structure | low | moderate | no | Storm patrol | Lower Big Sur | N7 | 36.25821N | 121.78811W |
| Big Sur Resorts | 617 | State park road | Residential structures along banks of channel | debris flow | Several houses | home | moderate | moderate | no | early warning system | Lower Big Sur | N7 | 36.25513N | 121.78676W |
| Big Sur Resorts | 618 | Highway 1 | Plugging 36" culvert, inlet appears to be cleaned out regularly, significant quantity of LWD in channel immediately upstream | debris flow | Culvert | drainage structure | low | high | no | Storm patrol, channel clearance | Lower Big Sur | N7 | 36.25958N | 121.78905W |
| Big Sur Resorts | 619 | Private road/highway 1 | Private abandoned road with switchback at channel, culvert under switchback with recently excavated inlet and newer standpipe at inlet. If plugged, diversion down insloped private road onto Highway 1. Also standpipe at recently exc. culvert inlet at Highway 1 | debris flow | Culverts, highway 1 | drainage structure | moderate | moderate | no | Storm patrol, diversion structure | Lower Big Sur | N7 | 36.26061N | 121.79072W |
| Big Sur Resorts | 620 | Fernwood Campground and Resort off Highway 1 | Fernwood campground/resort located in FEMA 100 yr flood plain along Big Sur River, tents, trailers, mobile and modular homes | flood | Campground facility | recreational | high | high | yes | no camping during storm events | Lower Big Sur | N7 | 36.26032N | 121.79388W |
| Big Sur Resorts | 621 | St. Francis of the Redwood Church off Highway 1 | St Francis of the redwoods church facility adjacent to Big Sur River, partially in FEMA 100 yr floodplain | flood | Church facility | other | high | high | no | early warning system | Lower Big Sur | N7 | 36.26365N | 121.79516W |
| Big Sur Resorts | 622 | Highway 1 | Several private residences located partially on FEMA 100 yr floodplain along Big Sur River, signs for "river house" and "tee house" | flood | Houses | home | high | high | no | early warning system | Lower Big Sur | N7 | 36.25593N | 121.79424W |
| Big Sur Resorts | 623 | Private road | Bridge in FEMA floodplain, access to four residential houses | flood | Bridge | drainage structure | moderate | moderate | yes | storm patrol | Lower Big Sur | N7 | 36.26400N | 121.80190W |
| Big Sur Resorts | 624 | private road | Several houses located across bridge on FEMA floodplain | flood | Houses | home | high | high | yes | early warning system | Lower Big Sur | N7 | 36.26391N | 121.80287W |
| Big Sur Resorts | 628 | Pfeiffer-Big Sur State Park | Channel appears to drain into wastewater facility | debris flow | Wastewater treatment facility | State Park | high | high | no | diversion structure | Lower Big Sur | N7 | 36.25694N | 121.78790W |

Note: These results were based upon a rapid review so that as much time as possible was allowed for emergency measures to be put in place before winter storms

| Community | Site Number | Address | Field Observation | Hazard Category | Feature | Feature Category | Hazard to Life | Hazard to Property | In FEMA/DWR 100 yr floodplain | Preliminary Emergency Protective Measures | Subwatershed (Tier 2) | Pour Point | Latitude (Decimal Degrees) | Longitude (Decimal Degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Big Sur Resorts | 631 | Highway 1 | River cabins downslope from ripple wood cabins sign on highway, numerous cabins on FEMA floodplain | flood | Cabins | home | high | high | yes | no camping during storm events | Lower Big Sur | N7 | | |
| Cachagua community | 160 | Nason road | Trailer park and other residences on FEMA floodplain and expansive flat area at confluence of Cachagua Creek and Carmel River | flood | Trailer park | multiple | high | high | yes | early warning system | Upper Carmel | 23 | | |
| Cachagua community | 161 | Nason road | Community park with swimming hole and recreation facilities on edge of FEMA floodplain. Park and children's center on broad flat area adjacent to channel | flood | Park, children center, swimming and rec | multiple | moderate | moderate | yes | early warning system | Upper Carmel | 23 | | |
| Cachagua syndicate camp | 155 | private road | Hughes residence in FEMA floodplain | flood | House | home | low | low | yes | early warning system | Upper Carmel | 19 | 36.40955N | 121.67608W |
| Cachagua syndicate camp | 163 | private road | Numerous residences in Carmel River floodplain, 1995 flooding reported | flood | houses | home | high | high | yes | early warning system | Upper Carmel | 19 | | |
| Carmel | 569 | Carmel River State Beach | Bathroom and parking lot in flood zone from Carmel River exit | flood | Infrastructure | recreational | no | moderate | yes | early warning system, staging, sandbag, muscle wall, etc | Lower Carmel | N1 | 36.53857N | 121.92743W |
| Carmel Valley Village | 162 | Garzas Road and Boranda Road area | numerous residences within FEMA floodplain | flood | Residential community | home | high | high | yes | early warning system | Lower Carmel | N2 | 36.49104N | 121.75123W |
| Coast Road | 551 | Coast Road Bridge on Bixby Creek | Bridge | debris flow / flood | Bridge | drainage structure | low | moderate | no | storm patrol | Middle Coastal | 30 | 36.36952N | 121.89244W |
| Coast Road | 552 | 39020 Coast Road | House is raised but structural suports in floodplain. Accessed via footbridge across channel. | debris flow / flood | House | home | high | high | no | early warning system | Middle Coastal | 30 | 36.37334N | 121.89790W |
| Coast Road | 553 | Coast Road - address not recorded | House in floodplain | debris flow / flood | House | home | high | high | no | early warning system | Middle Coastal | 30 | 36.37232N | 121.89697W |
| Coast Road | 554 | 39122 Coast Road | House, accessed via foot bridge in floodway | debris flow / flood | House | home | high | high | no | early warning system | Middle Coastal | 30 | 36.37166N | 121.89639W |
| Coast Road | 555 | 39198 Coast Road | Bridge access to house | debris flow / flood | Bridge | drainage structure | low | moderate | no | early warning system | Middle Coastal | 30 | 36.37149N | 121.89578W |
| Coast Road | 556 | 39208 Coast Road | House in floodway | debris flow / flood | House | home | high | high | no | early warning system | Middle Coastal | 30 | 36.37104N | 121.89540W |
| Coast Road | 557 | 39340 Coast Road | House in floodway | debris flow / flood | House | home | high | high | no | early warning system | Middle Coastal | 30 | 36.36990N | 121.89428W |
| Coast Road | 558 | Coast Road - address not recorded | House in floodway | debris flow / flood | House | home | high | high | no | early warning system | Middle Coastal | 30 | 36.37004N | 121.89354W |
| Coast Road | 559 | 39475 Coast Road | House, accessed via foot bridge in floodway | debris flow / flood | House and foot bridge | home | high | high | no | early warning system | Middle Coastal | 30 | 36.36842N | 121.89147W |
| Coast Road | 560 | 39509 Coast Road | House in floodway | debris flow / flood | House | home | high | high | no | early warning system | Middle Coastal | 30 | 36.36796N | 121.89139W |
| Coast Road | 561 | 39561 Coast Road | House, accessed via foot bridge in floodway | debris flow / flood | House and bridge | home | high | high | no | early warning system | Middle Coastal | 30 | 36.36728N | 121.89021W |
| Garrapata Creek | 127 | 36001 Garrapata Trout Farm Road | Number of residences/cabins constructed on floodplain and adjacent to side channel, some elevated on posts | debris flow / flood | Houses/cabins at Weston property | home | high | high | no | early warning system | Middle Coastal | N5 | 36.41442N | 121.90333W |
| Garrapata Creek | 128 | Garrapata Trout Farm Road | Airstream trailer in probable floodplain, adjacent stretch of road constructed in floodplain, only access for several residences upstream | flood | Airstream trailer | home | moderate | moderate | no | early warning system | Middle Coastal | N5 | 36.41662N | 121.90687W |
| Garrapata Creek | 130 | 35681 Garrapata Trout Farm Road | Private Residence on floodplain | flood | Houses | home | moderate | high | no | early warning system | Middle Coastal | N5 | 36.41543N | 121.91213W |
| Garrapata Creek | 131 | 35681 Garrapata Trout Farm Road | Cal American water company well that reportedly pumps water across creek to several residemces | flood | Water supply | utilities | no | moderate | no | early warning system | Middle Coastal | N5 | 36.41520N | 121.91219W |
| Garrapata State Park | 571 | Highway 1 | Potential Debris flow and flooding hazard to box culvert under highway 1 . Culvert is 8 feet tall, 6 feet wide | debris flow / flood | Box culvert | State Park | moderate | high | no | early warning system , communicate with CalTrans | Upper Coastal | 17 | 36.45596N | 121.92367W |
| Garrapata State Park | 572 | Highway 1 | Box culvert under highway 1, culvert is 7 feet tall, 6 feet wide, approx 35 feet fill over culvert | debris flow / flood | Box culvert | State Park | low | low | no | early warning system, storm patrol | Upper Coastal | 12 | 36.42182N | 121.91204W |
| Garrapatos Road | 545 | Bridge over Garrapatos Road | Bridge crossing over Garrapata Creek. Potential scour and debris plugging | debris flow / flood | Bridge | drainage structure | low | moderate | no | storm patrol | Middle Coastal | N5 | 36.39985N | 121.87265W |
| Garrapatos Road | 546 | 5910 Garrapatos Road | House at base of channel near confluence with potential debris flow channel | debris flow / flood | House | home | high | high | no | early warning system | Middle Coastal | N5 | 36.40021N | 121.87216W |

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| Community | Site Number | Address | Field Observation | Hazard Category | Feature | Feature Category | Hazard to Life | Hazard to Property | In FEMA/DWR 100 yr floodplain | Preliminary Emergency Protective Measures | Subwatershed (Tier 2) | Pour Point | Latitude (Decimal Degrees) | Longitude (Decimal Degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Garrapatos Road | 547 | 5933 Garrapatos Road | Foot bridge and house near channel floodway | debris flow / flood | Foot bridge and house | home | high | high | no | early warning system | Middle Coastal | N5 | 36.39977N | 121.87127W |
| Garrapatos Road | 548 | 59625 Garrapatos Road | Bridge crossing to residential properties | debris flow | Bridge | drainage structure | low | moderate | no | storm patrol | Middle Coastal | N5 | 36.39973N | 121.87076W |
| Garrapatos Road | 549 | 5947 Garrapatos Road | Bridge crossign to residential properties, plugging, scouring, etc | debris flow / flood | Bridge | drainage structure | low | moderate | no | storm patrol | Middle Coastal | 10 | 36.39992N | 121.86997W |
| Garrapatos Road | 550 | Garrapatos Road | Potential for scour and road fill failure along outside edge of creek. Residents reported that road prism failed during 1998 flooding. | debris flow / flood | Road | miscellaneous | moderate | moderate | no | storm patrol | Middle Coastal | N5 | 36.40015N | 121.87350W |
| Hoist | 500 | Main access to community | Potential for plugging of 18-inch diameter culvert | debris flow | Culvert | drainage structure | no | high | no | Clean culvert, storm patrol | Middle Coastal | 7 | 36.38011N | 121.84403W |
| Hoist | 501 | 38809 Palo Colorado Canyon Road | House within potential debris flow path | debris flow | House | home | high | high | no | early warning system | Middle Coastal | 7 | 36.38168N | 121.84203W |
| Hoist | 502 | Not recorded | potential for debris flow at low water ford crossing | debris flow | ford crossing | drainage structure | no | low | no | Storm patrol | Middle Coastal | 7 | 36.38435N | 121.83859W |
| Hoist | 503 | Not recorded | 36" culvert plugging potential | debris flow | Culvert | drainage structure | no | moderate | no | Storm patrol | Middle Coastal | 7 | 36.38632N | 121.83868W |
| Hoist | 504 | Not recorded | 36" culvert plugging potential | debris flow | Culvert | drainage structure | no | moderate | no | Storm patrol | Middle Coastal | 7 | 36.38622N | 121.84008W |
| Hoist | 505 | 38753 Palo Colorado Canyon Road | Yurt-cabin. Swale behind house/yurt | debris flow | House | home | moderate | moderate | no | early warning system | Middle Coastal | 7 | 36.38643N | 121.84170W |
| Hoist | 506 | 38741 Palo Colorado Canyon Road | Home on edge of creek | debris flow | House | home | high | high | no | early warning system | Middle Coastal | 7 | 36.38798N | 121.83755W |
| Joshua Creek | 109 | Private road | Potential for plugging of 48-inch diameter culvert from debris flow, possible diversion onto paved road | debris flow | Culvert/road | drainage structure | low | moderate | no | Storm patrol | Middle Coastal | N4 | 36.42097N | 121.89093W |
| Joshua Creek | 110 | Private road | Burned out ditch relief culvert, erosion potential | other | Private road | drainage structure | no | moderate | no | Repair/replace culvert | Middle Coastal | N4 | 36.42098N | 121.89171W |
| Joshua Creek | 111 | Jeep road | Stringer bridge for jeep road on Joshua Creek, very little capacity, likely to overtop or blow out | debris flow / flood | Stringer bridge | drainage structure | low | low | no | Storm patrol | Middle Coastal | N4 | 36.42035N | 121.89194W |
| Joshua Creek | 112 | Private road | 48" culvert with dug out inlet, debris flow plugging potential | debris flow | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | N4 | 36.42083N | 121.89257W |
| Joshua Creek | 113 | Private road | Erosion of burned out ditch relief culvert | other | Private road | drainage structure | low | low | no | Repair/replace culvert | Middle Coastal | N4 | 36.41940N | 121.89535W |
| Joshua Creek | 114 | Private road | 24" plastic culvert, potential for plugging at inlet, outlet is burned, extent of damage unknown | debris flow | Culvert, road | drainage structure | low | low | no | Storm patrol, repair/replace culvert | Middle Coastal | N4 | 36.42006N | 121.89634W |
| Joshua Creek | 115 | Private road | Burned out culvert crossing with two water tanks in channel below road, potential for debris flow to impact road/water tanks | debris flow | Road and water tanks | multiple | low | moderate | no | Storm patrol | Middle Coastal | N4 | 36.42303N | 121.89043W |
| Joshua Creek | 116 | Private road | Steel plate Bridge with gabion abutments | debris flow | Bridge | drainage structure | low | low | no | Storm patrol | Middle Coastal | N4 | 36.42309N | 121.89009W |
| Joshua Creek | 117 | Private road | Water supply/spring with steel pipes in channel that drain to tanks at VAR 115, likely to be destroyed in debris flow | debris flow | Water supply | other | low | moderate | no | Storm patrol | Middle Coastal | N4 | 36.42331N | 121.88967W |
| Joshua Creek | 118 | Private road | Debris flow- potential for scour around right abutment of bridge, plugging with large woody debris | debris flow / flood | Bridge | drainage structure | low | moderate | no | Storm Patrol | Middle Coastal | N4 | 36.42272N | 121.88272W |
| Joshua Creek | 119 | Private road | Segment of road with at least 3 burned out plastic ditch relief culverts | other | Private Road | drainage structure | low | low | no | Repair/replace culverts | Middle Coastal | N4 | 36.42128N | 121.88120W |
| Joshua Creek | 120 | Private road | Potential for plugging of culvert | debris flow | Culvert | drainage structure | low | moderate | no | Storm patrol | Middle Coastal | N4 | 36.42297N | 121.88390W |
| Joshua Creek | 121 | Private road | Burned out culvert, potential for plugging and/or erosion | debris flow | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | N4 | 36.42305N | 121.88770W |
| Joshua Creek | 122 | Private road | Potential for culvert plugging | debris flow | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | N4 | 36.42301N | 121.89244W |
| Joshua Creek | 123 | Private road | Potential for culvert plugging | debris flow | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | N4 | 36.42171N | 121.89587W |
| Joshua Creek | 124 | 35811 Garrapata Trout Farm Road | Residence/studio near channel, resident reports 98 flood came very close. Resident report that home is not primary residence | debris flow / flood | Studio/residence | home | moderate | high | no | early warning system | Middle Coastal | N4 | 36.41694N | 121.90325W |

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| Community | Site Number | Address | Field Observation | Hazard Category | Feature | Feature Category | Hazard to Life | Hazard to Property | In FEMA/DWR 100 yr floodplain | Preliminary Emergency Protective Measures | Subwatershed (Tier 2) | Pour Point | Latitude (Decimal Degrees) | Longitude (Decimal Degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Joshua Creek | 125 | 35811 Garrapata Trout Farm Road | Low bridge span, lots of large woody debris observed upstream, small sheds on either side on floodplain, previous Arizona crossing destroyed in 98 (reported by owner) | debris flow / flood | Bridge,water tank, and two sheds | multiple | low | high | no | Storm Patrol | Middle Coastal | N4 | 36.41668N | 121.90371W |
| Joshua Creek | 126 | 36001 Garrapata Trout Farm Road | 6' culvert, potential plugging/overtopping hazard, upstream landowner reports that 98 flood destroyed previous bridge at this location | debris flow / flood | Culvert | drainage structure | low | moderate | no | Storm patrol | Middle Coastal | N4 | 36.41591N | 121.90488W |
| Juan Higuera Creek | 582 | Not recorded | Debris flow | debris flow / flood | Homes and big Sur grange | home | high | high | yes | early warning system | Lower Big Sur | N7 | | |
| Little Sur | 613 | Old Coast Road | Bailey Bridge | Flood | Bridge | drainage structure | no | low | yes | storm patrol | Little Sur | 4 | 36.33046N | 121.86257W |
| Malpaso creek | 165 | San Remo Road | Water wells and conveyance pipeline located near/within river channel | debris flow / flood | Water wells and conveyance pipeline | utilities | low | high | no | storm patrol | Upper Coastal | 18 | 36.47881N | 121.91668W |
| NPWMD fish hatchery | 200 | Near San Clemente Dam | Flooding, no inhabitants | flood | Hatchery infrastructure | other | no | low | no | Remove pumps next to active channel prior to winter rains | Upper Carmel | N3 | 36.44396N | 121.71513W |
| Old Coast Road | 603 | Old Coast Road | Potential for plugging of 48" diameter culvert and diversion down road | flood | Culvert | drainage structure | no | moderate | no | storm patrol, install critical dip | Middle Coastal | 30 | 36.35469N | 121.87819W |
| Old Coast Road | 604 | Old Coast Road | Potential for plugging of 48" diameter culvert and diversion down road. | flood | Culvert | drainage structure | no | moderate | no | storm patrol, install critical dip | Middle Coastal | 30 | 36.35408N | 121.87734W |
| Old Coast Road | 605 | Old Coast Road | Potential for plugging of 60" diameter culvert .  No access past locked gate. | debris flow / flood | Culvert | drainage structure | no | moderate | no | storm patrol | Middle Coastal | 30 | 36.35269N | 121.87699W |
| Old Coast Road | 606 | Old Coast Road | Potential for plugging of two 48" diameter culverts and diversion down road. | debris flow / flood | Culvert | drainage structure | no | moderate | no | storm patrol, install critical dip | Middle Coastal | 30 | 36.35153N | 121.87696W |
| Old Coast Road | 607 | Old Coast Road | Potential for plugging of 48" diameter culvert and diversion down road. | debris flow / flood | Culvert | drainage structure | no | moderate | no | storm patrol, install critical dip | Middle Coastal | 30 | 36.35021N | 121.87621W |
| Old Coast Road | 608 | Old Coast Road | Potential for plugging of 48" diameter culvert and diversion down road. | debris flow / flood | Culvert | drainage structure | no | moderate | no | storm patrol, install critical dip | Middle Coastal | 30 | 36.34572N | 121.87202W |
| Old Coast Road | 609 | Old Coast Road | Potential for plugging of 48" diameter culvert and diversion down road. | debris flow / flood | Culvert | drainage structure | no | low | no | storm patrol, install critical dip | Middle Coastal | 30 | 36.34531N | 121.87066W |
| Old Coast Road | 610 | Old Coast Road | Old cabin on floodplain | debris flow / flood | House | home | high | high | no | early warning system (if inhabited) | Middle Coastal | 30 | 36.34515N | 121.87000W |
| Old Coast Road | 611 | Old Coast Road | 24" plastic pipe-burned out ditch relief culvert. Potential for road collapse | Other | Culvert | drainage structure | no | high | no | Replace culvert | Middle Coastal | 30 | 36.34471N | 121.86754W |
| Old Coast Road | 612 | Old Coast Road | Potential for flooding and plugging of 48" diameter culvert | debris flow / flood | Culvert | drainage structure | no | moderate | no | storm patrol | Middle Coastal | 30 | 36.34514N | 121.86586W |
| Palo Colorado | 100 | Turner Creek bridge along Palo Colorado Canyon Road | potential scour to bridge abutment, may undermine foundation, crib wall burned, road access pico blanco Boy Scout camp | debris flow | Bridge | drainage structure | low | moderate | no | early warning system | Middle Coastal | 30 | 36.37352N | 121.83684W |
| Palo Colorado | 102 | Below Palo Colorado Canyon Road | potential debris flow over road and down steep slope toward residence | debris flow | Residence | home | moderate | moderate | no | early warning system, diversion structures | Middle Coastal | 30 | 36.36643N | 121.82969W |
| Palo Colorado | 103 | 38115 Palo Colorado Canyon Road | 60"' culvert with half plugged 48" overflow culvert, plugging potential, neighbors reported past plugging and blow out | debris flow / flood | Culvert | drainage structure | low | moderate | no | Storm patrol, clean out overflow culvert | Middle Coastal | 7 | 36.38147N | 121.86319W |
| Palo Colorado | 104 | 38115 Palo Colorado Canyon Road | Residence in close proximity to floodplain | flood | House | home | high | high | no | early warning system | Middle Coastal | 7 | 36.38063N | 121.86156W |
| Palo Colorado | 105 | Palo Colorado Canyon Road | 30" culvert - potential plugging from debris flow/flood | debris flow / flood | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | 7 | 36.38333N | 121.86463W |
| Palo Colorado | 106 | Palo Colorado Canyon Road | 6.5' culvert with plugging potential, upstream appears to be old skid trail with high volume of stored sediment, would divert down road to next crossing | flood | culvert | drainage structure | low | moderate | no | Storm patrol | Middle Coastal | 9 | 36.38982N | 121.87128W |
| Palo Colorado | 107 | Palo Colorado Canyon Road | 6.5' Culvert with plugging potential and potential diversion down Palo Colorado Canyon Road | flood | Culvert | drainage structure | low | moderate | no | Storm patrol | Middle Coastal | 8 | 36.38982N | 121.87216W |

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| Community | Site Number | Address | Field Observation | Hazard Category | Feature | Feature Category | Hazard to Life | Hazard to Property | In FEMA/DWR 100 yr floodplain | Preliminary Emergency Protective Measures | Subwatershed (Tier 2) | Pour Point | Latitude (Decimal Degrees) | Longitude (Decimal Degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Palo Colorado | 108 | 37732 Palo Colorado Canyon Road | 6' culvert at driveway, overhanging stringer logs at outlet, plugging potential, would divert toward residence | flood | Culvert and residence | home | high | high | no | early warning system, Storm patrol | Middle Coastal | 8 | 36.39102N | 121.87496W |
| Palo Colorado | 132 | Palo Colorado Canyon Road | potential plugging of 24" culvert | debris flow | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | 30 | 36.35571N | 121.81500W |
| Palo Colorado | 133 | Palo Colorado Canyon Road | potential plugging of 18" culvert, crib logs along outside edge of road are burned with near vertical crumbling fill exposed | debris flow | Culvert/road | drainage structure | low | moderate | no | Storm patrol | Middle Coastal | 30 | 36.35678N | 121.81659W |
| Palo Colorado | 134 | Palo Colorado Canyon Road | Bridge over Mill Creek. Possible debris jam and overtopping | debris flow | Bridge | drainage structure | low | low | no | Storm patrol | Middle Coastal | 30 | 36.36167N | 121.82193W |
| Palo Colorado | 135 | Palo Colorado Canyon Road | potential plugging of 24" culvert with standpipe inlet | debris flow | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | 30 | 36.36259N | 121.82372W |
| Palo Colorado | 136 | Palo Colorado Canyon Road | potential plugging of 36" culvert | debris flow | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | 30 | 36.36431N | 121.82596W |
| Palo Colorado | 137 | Palo Colorado Canyon Road | potential plugging of 36" culvert | debris flow | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | 30 | 36.36818N | 121.83112W |
| Palo Colorado | 138 | Palo Colorado Canyon Road | potential plugging of 30" culvert | debris flow | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | 30 | 36.36844N | 121.83135W |
| Palo Colorado | 139 | Palo Colorado Canyon Road | potential plugging of 36" culvert and diversion down road | debris flow | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | 30 | 36.37407N | 121.84015W |
| Palo Colorado | 140 | Palo Colorado Canyon Road | potential plugging of 12" culvert with diversion potential | debris flow | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | 30 | 36.37409N | 121.84336W |
| Palo Colorado | 141 | Palo Colorado Canyon Road | potential plugging of standpipe inlet and diversion down road | debris flow | Culvert | drainage structure | low | low | no | Storm patrol | Middle Coastal | 30 | 36.37558N | 121.84677W |
| Palo Colorado | 507 | 38711 Palo Colorado Canyon Road | potential for scour, noted steel tank and large woody debris within active channel | debris flow | Bridge | drainage structure | low | high | no | storm patrol | Middle Coastal | 7 | 36.37819N | 121.85181W |
| Palo Colorado | 508 | 38250 Palo Colorado Canyon Road | 55" culvert with plugging potential | debris flow / flood | Culvert | drainage structure | no | moderate | no | Storm patrol | Middle Coastal | 7 | 36.38287N | 121.86867W |
| Palo Colorado | 509 | 38240 Palo Colorado Canyon Road | Squashed culvert 5'x6' with plugging potential | debris flow / flood | Culvert | drainage structure | no | moderate | no | Storm patrol | Middle Coastal | 7 | 36.38276N | 121.86660W |
| Palo Colorado | 510 | Green Ridge Road | 24" culvert with potential plugging | debris flow / flood | Culvert | drainage structure | no | moderate | no | Storm patrol | Middle Coastal | 9 | 36.39027N | 121.85960W |
| Palo Colorado | 511 | Green Ridge Road | 12" culvert with potential plugging | debris flow / flood | Culvert | drainage structure | no | moderate | no | Storm patrol | Middle Coastal | 9 | 36.39123N | 121.85898W |
| Palo Colorado | 512 | Green Ridge Road | 36"x48" culvert with plugging potential | debris flow / flood | Culvert | drainage structure | no | moderate | no | Storm patrol | Middle Coastal | 9 | 36.39374N | 121.85756W |
| Palo Colorado | 513 | 37740 Palo Colorado Canyon Road | 5' culvert at driveway for 37740 Palo Colorado | flood | Culvert | drainage structure | no | moderate | no | Storm patrol, stream clearing | Middle Coastal | 8 | 36.38997N | 121.87410W |
| Palo Colorado | 514 | 37748 Palo Colorado Canyon Road | 6' culvert at driveway for 37748 Palo Colorado | flood | Culvert | drainage structure | no | moderate | no | Storm patrol, stream clearing | Middle Coastal | 8 | 36.38966N | 121.87297W |
| Palo Colorado | 515 | 37715 Palo Colorado Canyon Road | Potential for debris flow/flooding diversion on to Garrapatos Road | debris flow / flood | Road | drainage structure | low | moderate | no | Storm patrol | Middle Coastal | 8 | 36.39222N | 121.87435W |
| Palo Colorado | 516 | 37699 Palo Colorado Canyon Road | Home near Palo Colorado Creek | debris flow / flood | House | home | high | high | no | early warning system | Middle Coastal | 8 | 36.39196N | 121.87627W |
| Palo Colorado | 517 | 37691 Palo Colorado Canyon Road | Home near Palo Colorado Creek | debris flow / flood | House | home | high | high | no | early warning system | Middle Coastal | 8 | 36.39244N | 121.87675W |
| Palo Colorado | 518 | 37523 Palo Colorado Canyon Road | House near Palo Colorado Creek, noted railroad ties along bank - potential bank scour | flood | House | home | high | high | no | early warning system | Middle Coastal | 8 | 36.39343N | 121.87746W |
| Palo Colorado | 519 | 37497 Palo Colorado Canyon Road | 5' diameter culvert under driveway to house, potential plugging | flood | Culvert/driveway | drainage structure | low | high | no | early warning system and storm patrol | Middle Coastal | 8 | 36.39377N | 121.87789W |
| Palo Colorado | 520 | 37455 Palo Colorado Canyon Road | Concrete box culvert 5'x10', potential plugging | flood | Road | drainage structure | low | high | no | storm patrol, clear debris from house pad above | Middle Coastal | 8 | 36.39447N | 121.87861W |
| Palo Colorado | 521 | 37452 Palo Colorado Canyon Road | Home near Palo Colorado Creek | flood | House | home | high | high | no | early warning system | Middle Coastal | 8 | 36.39463N | 121.87881W |
| Palo Colorado | 522 | 37400 Palo Colorado Canyon Road | Crossing under Palo Colorado Canyon Road. 6' diameter culvert connected to 8' diameter culvert is undermined | flood | Road | drainage structure | low | high | no | storm patrol, repair undermine culvert | Middle Coastal | 8 | 36.39526N | 121.87922W |
| Palo Colorado | 523 | Bridge to Garrapatos Road | Bridge west of intersection of Garrapatos and Palo Colorado Canyon Road | flood | Bridge | drainage structure | low | moderate | no | Storm patrol, early warning system | Middle Coastal | 8 | 36.39526N | 121.87952W |
| Palo Colorado | 524 | 37341 Palo Colorado Canyon Road | Home near Palo Colorado Creek channel | flood | House | home | high | high | no | early warning system | Middle Coastal | 8 | 36.39601N | 121.88043W |
| Palo Colorado | 525 | 37315 Palo Colorado Canyon Road | House, garage, and driveway bridge on Palo Colorado Creek. House is above channel, garage is lower and at higher risk. Driveway bridge at moderate risk. | flood | House/Bridge | home/drainage structure | low | moderate | no | early warning system, storm patrol | Middle Coastal | 8 | 36.39599N | 121.88048W |
| Palo Colorado | 526 | 37305 Palo Colorado Canyon Road | Driveway bridge to house at risk, house above street elevation | flood | Bridge | drainage structure | low | moderate | no | early warning system, strom patrol | Middle Coastal | 8 | 36.39670N | 121.88158W |

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| Community | Site Number | Address | Field Observation | Hazard Category | Feature | Feature Category | Hazard to Life | Hazard to Property | In FEMA/DWR 100 yr floodplain | Preliminary Emergency Protective Measures | Subwatershed (Tier 2) | Pour Point | Latitude (Decimal Degrees) | Longitude (Decimal Degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Palo Colorado | 527 | 37295 Palo Colorado Canyon Road | Foot bridge access to house | flood | Foot Bridge | drainage structure | low | moderate | no | early warning system | Middle Coastal | 8 | 36.39674N | 121.88214W |
| Palo Colorado | 528 | Palo Colorado Canyon Road | 5' diameter culvert under Palo Colorado Canyon Road | flood | Culvert | drainage structure | no | high | no | storm patrol, stream clearance | Middle Coastal | 8 | 36.39877N | 121.88663W |
| Palo Colorado | 529 | Palo Colorado Canyon Road | Culvert - 5' diameter. Concrete wingwalls under Palo Colorado Canyon Road | Flood | Culvert | drainage structure | no | low | no | Channel clearance, storm patrol | Middle Coastal | 8 | 36.39942N | 121.88838W |
| Palo Colorado | 530 | 37029 Palo Colorado Canyon Road | Two foot bridges access house under construction. Palo Colorado Creek makes meander at house | Flood | House | home | low | moderate | no | early warning system | Middle Coastal | 8 | 36.39970N | 121.89055W |
| Palo Colorado | 531 | 37021 Palo Colorado Canyon Road | foot bridge access to patio | Flood | Patio | foot bridge and patio | low | moderate | no | early warning system | Middle Coastal | 8 | 36.39979N | 121.89205W |
| Palo Colorado | 532 | 37013 Palo Colorado Canyon Road | Driveway bridge to access house. House not at risk. | Flood | Bridge | drainage structure | no | moderate | no | early warning system | Middle Coastal | 8 | 36.40005N | 121.89286W |
| Palo Colorado | 533 | 37005 Palo Colorado Canyon Road | Foot bridge to house and propane tank | Flood | Bridge | drainage structure | no | moderate | no | early warning system | Middle Coastal | 8 | 36.40044N | 121.89453W |
| Palo Colorado | 534 | Palo Colorado Canyon Road | Driveway bridge to access house. House not at risk. | Flood | Bridge | drainage structure | no | moderate | no | early warning system | Middle Coastal | 8 | 36.40077N | 121.89488W |
| Palo Colorado | 535 | 36971 Palo Colorado Canyon Road | House near Palo Colorado Creek | Flood | House | home | high | high | no | early warning system | Middle Coastal | 8 | 36.40084N | 121.89499W |
| Palo Colorado | 536 | 36967 Palo Colorado Canyon Road | Lower house, foot bridge near Palo Colorado Creek channel | Flood | House | home | high | high | no | early warning system | Middle Coastal | 8 | 36.40111N | 121.89562W |
| Palo Colorado | 537 | 36963 Palo Colorado Canyon Road | Cabin built over watercoure, was told water flows through windows during flood flows | Flood | House | home | high | high | no | early warning system | Middle Coastal | 8 | 36.40116N | 121.89575W |
| Palo Colorado | 538 | 36959 Palo Colorado Canyon Road | Deck foundations could scour, and foot bridge that accesses house at risk | Flood | House | home | moderate | high | no | early warning system | Middle Coastal | 8 | 36.40121N | 121.89670W |
| Palo Colorado | 539 | 36955 & 36951 Palo Colorado Canyon Road | Potential scour of foundations for driveway bridges. Homes not at risk. | Flood | Bridge | drainage structure | low | moderate | no | early warning system | Middle Coastal | 8 | 36.40117N | 121.89748W |
| Palo Colorado | 540 | 36947 Palo Colorado Canyon Road | Driveway bridge to access house. House not at risk. | Flood | Bridge | drainage structure | low | moderate | no | early warning system | Middle Coastal | 8 | 36.40133N | 121.89832W |
| Palo Colorado | 541 | 36943 Palo Colorado Canyon Road | House low in channel. Foundation piers scoured and appear unsafe. | Flood | House | home | high | high | no | early warning system | Middle Coastal | 8 | 36.40153N | 121.89901W |
| Palo Colorado | 542 | 36925 Palo Colorado Canyon Road | Residence accessed via foot bridge over creek, potential scour of structural footings in channel flood zone | Flood | Foot bridge | home | high | high | no | early warning system | Middle Coastal | 8 | 36.40136N | 121.89896W |
| Palo Colorado | 543 | 36935 and 36933 Palo Colorado Canyon Road | Bridge and water supply pipes within active channel | Flood | Residential access and infrastructure | home | low | moderate | no | early warning system | Middle Coastal | 8 | 36.40112N | 121.89979W |
| Palo Colorado | 544 | Palo Colorado Canyon Road | 8'x6' concrete box culvert. Poor condition | Flood | Culvert | road | no | moderate | no | storm patrol | Middle Coastal | 8 | 36.39987N | 121.90242W |
| Palo Colorado | 600 | 5953 Garrapatos Road | Home, driveway, bridge, walkway, and propane tank at risk to flooding | flood | house | home | high | high | no | early warning system | Middle Coastal | 10 | 36.40150N | 121.86794W |
| Palo Colorado | 601 | 5922 Garrapatos Road | 5th wheel, outbuildings, and pedestrian bridge at risk to flooding | flood | house | home | moderate | high | no | early warning system | Middle Coastal | 10 | 36.40093N | 121.86895W |
| Palo Colorado | 602 | Garrapatos Road | Road at risk to flooding and washout which may limit access to upstream. Currently armored with crib logs. | flood | road | other | no | moderate | no | early warning system | Middle Coastal | 10 | 36.40038N | 121.86909W |
| Palo Colorado | 625 | Green Ridge Road area | Potential plugging of 2x36" culvert crossing, only access to house. | debris flow / flood | Culverts | drainage structure | low | moderate | no | Storm patrol | Middle Coastal | 9 | 36.38959N | 121.86540W |
| Palo Colorado | 626 | Green Ridge Road area | Tributary crossing with no drainage structure, drains on to road and down to main channel at point 625, debris piled immediately upstream of the road | debris flow | Road | drainage structure | low | moderate | no | storm patrol | Middle Coastal | 9 | 36.38994N | 121.86535W |
| Palo Colorado | 627 | Green Ridge Road area | Plugging of burned out culvert that goes under bocce ball court and parking area with sheds, plugging and overtopping may direct flow towards residence | debris flow | House, pad w/ bocce court and sheds | home | moderate | high | no | early warning system, replace culvert, diversion structure | Middle Coastal | 9 | 36.39018N | 121.86412W |
| Pfeiffer-Big Sur State Park | 574 | Highway 1 | large waste treatment facility, existing H-beam and wood lagging protects facility infrastucture from debris flow; additional protection needed | debris flow | Offices and generator | State Park | high | high | no | Install k rail along buildings, remove hazard trees perched over facilities | Lower Big Sur | N7 | 36.25754N | 121.78769W |

Note: These results were based upon a rapid review so that as much time as possible was allowed for emergency measures to be put in place before winter storms

| Community | Site Number | Address | Field Observation | Hazard Category | Feature | Feature Category | Hazard to Life | Hazard to Property | In FEMA/DWR 100 yr floodplain | Preliminary Emergency Protective Measures | Subwatershed (Tier 2) | Pour Point | Latitude (Decimal Degrees) | Longitude (Decimal Degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pfeiffer-Big Sur State Park | 575 | Highway 1 | Potential debris flow into Pfeiffer/Big Sur-Redwood Creek Lodge, parking lot, highway 1, and drainage structures. Documented history of debris flow in this area | debris flow | Pfeiffer Big Sur Lodge | State Park | high | high | no | Protect north and east sides of lodge with k rails, block half of access road above lodge with k rail. Close parking lot during winter | Lower Big Sur | N7 | 36.25099N | 121.78639W |
| Pfeiffer-Big Sur State Park | 576 | Pfeiffer-Big Sur Road | potential flooding of Junior Ranger building and lift station that pumps sewage | flood | Building, lift station | State Park | low | moderate | no | Sand bagging and plywood | Upper Big Sur | N6 | 36.25045N | 121.78456W |
| Pfeiffer-Big Sur State Park | 577 | Pfeiffer-Big Sur Road | Potential debris flow route into restroom building in campground | debris flow | Bathrooms | State Park | low | low | no | Sand bagging and plywood | Upper Big Sur | N6 | 36.25068N | 121.78174W |
| Pfeiffer-Big Sur State Park | 578 | Day use entrance road | Rock fall hazard and debris flow impacts to road , this road is main public access . | rock fall, debris flow | Road | State Park | moderate | moderate | yes | early warning system, general awareness, develop rock fall hazard mitigation | Upper Big Sur | N6 | 36.24790N | 121.77736W |
| Pfeiffer-Big Sur State Park | 579 | Pfeiffer-Big Sur State Park Employee Housing | potential flooding of residential housing | flood | homes | State Park | low | moderate | yes | early warning system, muscle wall to close the breach in the berm. Berm wraps around housing buildings | Upper Big Sur | N6 | 36.24504N | 121.77578W |
| Pfeiffer-Big Sur State Park | 580 | Pfeiffer-Big Sur Road | Potential flooding in campground area | flood | Recreation | State Park | moderate | moderate | yes | Close during raiming season | Upper Big Sur | N6 | 36.24605N | 121.77889W |
| Pfeiffer-Big Sur State Park | 581 | Pfeiffer-Big Sur Campground | Lift station for sewage, generator, important infrastructure | flood | Recreation, Infrastructure | State Park | low | high | yes | Sand bagging , plywood | Upper Big Sur | N6 | 36.24985N | 121.78435W |
| Pico Blanco Boy Scout camp | 101 | End of Palo Colorado Canyon Road | Campsites in close proximity to channel / on floodplain | debris flow / flood | Boy Scout camp | recreational | high | moderate | yes | During storm events close campground by closing access road past gate | Little Sur | 25 | 36.33116N | 121.79461W |
| San Clemente Rancho | 148 | Black Rock Road | Number of homes constructed on boulder strewn alluvial fan at mouth of Black Rock Creek | debris flow / flood | Numerous residences | home | high | high | yes | early warning system | Upper Carmel | 28 | | |
| San Clemente Rancho | 149 | Dormody Road | Numerous houses constructed on floodplain or close to channel, along San Clemente Creek below Black Rock Creek alluvial fan | debris flow / flood | Houses | home | high | high | yes | early warning system | Upper Carmel | 20 | | |
| San Clemente Rancho | 150 | Dormody Road | Community center and recreational facilities in floodplain | debris flow / flood | Community center | recreational | high | high | no | early warning system | Upper Carmel | 20 | 36.42210N | 121.73231W |
| San Clemente Rancho | 151 | Dormody Road | Debris flow/flooding impact at bridge and other crossing structures on Black Rock Creek alluvial fan | debris flow / flood | Bridge/other crossing structures on fan | drainage structure | moderate | high | no | early warning system, storm patrol | Upper Carmel | 20 | 36.42240N | 121.73841W |
| San Clemente Rancho | 152 | 18 Dormody Road | Backwater flooding immediately upstream of confluence with Black Rock Creek | flood | House | home | high | high | no | early warning system | Upper Carmel | 27 | 36.42244N | 121.73921W |
| San Jose Creek | 570 | San Jose Creek Canyon Road | state park residences located on floodplain | flood | Residences | State Park | low | moderate | yes | early warning system, implement state parks previous mitigations | Upper Coastal | 21 | 36.51970N | 121.92092W |
| Santa Lucia Preserve | 143 | 54 Rancho San Carlos Road | Residence under construction on alluvial fan adjacent to tributary channel | debris flow | Residence | home | low | low | no | early warning system | Upper Coastal | 21 | 36.46562N | 121.83299W |
| Santa Lucia Preserve | 144 | Garzas Trail | Potential plugging of approx 60" culvert crossing on dirt road at locked gate. Unclear if additional residence upstream | debris flow / flood | Culvert | drainage structure | low | low | no | Storm patrol | Lower Carmel | N2 | 36.44174N | 121.82028W |
| Santa Lucia Preserve | 145 | Garzas Trail | Bridge in FEMA floodplain | flood | Bridge | drainage structure | low | low | yes | Storm patrol | Lower Carmel | N2 | 36.44818N | 121.81909W |
| Santa Lucia Preserve | 146 | Rancho San Carlos Road | 10' x 4' squash culvert on Las Gazas Creek, appears undersized based on channel width | flood | Culvert | drainage structure | low | low | yes | Storm patrol | Lower Carmel | N2 | 36.45414N | 121.80752W |
| Santa Lucia Preserve | 147 | Foot path in summer camp | Footbridge with center pier subject to flooding | flood | Foot bridge | drainage structure | low | low | yes | Storm patrol | Lower Carmel | N2 | 36.45557N | 121.80613W |
| Santa Lucia Preserve | 630 | 46 Rancho San Carlos Road | Residence appears to be constructed on edge of alluvial fan, potential debris flow impact | debris flow | house | home | low | low | no | early warning system | Upper Coastal | 21 | 36.47085N | 121.84128W |
| Upper Carmel River | 156 | private road upstream of syndicate | A-frame residence Immediately adjacent to active channel, footbridge over river behind house | flood | Private residence | home | high | high | no | early warning system | Upper Carmel | 19 | 36.40957N | 121.67300W |

Note: These results were based upon a rapid review so that as much time as possible was allowed for emergency measures to be put in place before winter storms

| Community | Site Number | Address | Field Observation | Hazard Category | Feature | Feature Category | Hazard to Life | Hazard to Property | In FEMA/DWR 100 yr floodplain | Preliminary Emergency Protective Measures | Subwatershed (Tier 2) | Pour Point | Latitude (Decimal Degrees) | Longitude (Decimal Degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Upper Carmel River | 157 | Private road | Debris flow - House in close proximity to channel, locked gate and fence | debris flow | House | home | moderate | moderate | no | early warning system | Upper Carmel | 19 | 36.40472N | 121.67023W |
| Upper Carmel River | 158 | Private road | potential plugging 18" culvert, evidence of previous plugging | debris flow | Culvert | drainage structure | low | moderate | no | Storm patrol | Upper Carmel | 19 | 36.40534N | 121.67236W |
| Upper Carmel River | 159 | Private road | Bridge, reportedly OK in 95 flood | flood | Bridge | drainage structure | low | low | yes | storm patrol | Upper Carmel | 19 | 36.40850N | 121.67243W |
| Upper Carmel River | 201 | Private road, upstream of San Clemente Dam site | Hunting cabin, uninhabited | flood | hosue | recreational | no | low | no | None needed | Upper Carmel | 19 | 36.42189N | 121.71134W |
| White Rock | 153 | Robinson Canyon Road | Low bridge crossing with several homes upstream | debris flow / flood | Bridge | drainage structure | low | moderate | no | Storm patrol | Upper Carmel | 20 | 36.41062N | 121.78097W |
| White Rock | 154 | 94 Robinson Canyon Road | House in floodplain with sandbag wall showing evidence of recent flooding | debris flow / flood | House | home | high | high | no | early warning system | Upper Carmel | 20 | 36.41052N | 121.78090W |

* gray = larger communities rather than individual features

Note: These results were based upon a rapid review so that as much time as possible was allowed for emergency measures to be put in place before winter storms

## General Recommendations

Early Warning System - Existing early warning systems should be used and improved such that residents can be alerted to incoming storms, allowing enough time to safely vacate hazard areas. Practical lead times of several hours must come from a combination of weather forecasts, rainfall measurements of approaching storms, and debris-flow triggering thresholds. Please see text (Section 4.5, general recommendations) for a discussion.

Storm Patrol - Existing road drainage systems should be inspected for damage or plugging by the appropriate controlling agency to evaluate potential impacts from floods, hyperconcentrated floods, debris torrents, debris flows and sedimentation resulting from storm events.

Structure Protection - Please see text (Section 4.5, general recommendations) for a discussion.

Temporary Housing - Please see text (Section 4.5, general recommendations) for a discussion.

**i. Lower Carmel @Mouth**

- Develop flood protection measures for the Carmel State Beach parking lot and bathroom structure.
- Flood hazards analyses may need to consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris.

**ii. Gazas Creek @ Carmel River**

- Develop an early warning system for residents in the FEMA 100-year flood zone (VAR 162).
- Develop a storm watch patrol for points in the Santa Lucia Preserve (VAR 144 - 147) so that watercourse crossings may be observed for blockage and cleaned out after storms.

**iii. San Clemente**

- A bulking factor to flow analysis should be considered for “watch stream” segments when designing mitigations. It has been our experience that a bulking factor of 50 percent has been used in other post-fire responses.
- *White Rock Community, Rancho San Clemente Community* (VAR 148-154): Early warning system, storm patrol

**iv. Carmel River @ San Clemente Dam**

- Because “watch stream” flood hazards are present any flood analyses should consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris.
- An early warning system tied to predicted storm events should be developed for these areas. Because cell reception is poor in these areas a reverse 911 or “nixle” system may not provide an adequate warning system.

**v. Carmel River @ Cachuaga**

- Because “watch stream” flood hazards are present any flood analyses should consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris.

**vi. Joshua Creek/Lower Garrapata Creek**

- Storm Patrol, Replace any existing plastic culverts that were destroyed in the fire.

**vii. Palo Colorado Community**

- Because “watch stream” flood hazards are present any flood analyses should consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris.
- An early warning system tied to predicted storm events should be developed for the Palo Colorado and Lower Bixby communities. This includes residential structures and road drainage features along Palo Colorado Road. Because cell reception is poor in these areas a reverse 911 or “nixle” system may not provide an adequate warning system.

**viii. Bixby Creek**

- Because “watch stream” flood hazards are present any flood analyses should consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris.
- An early warning system tied to predicted storm events should be developed for the Palo Colorado and Lower Bixby communities. This includes residential structures and road drainage features along Palo Colorado Road. Because cell reception is poor in these areas a reverse 911 or “nixle” system may not provide an adequate warning system.

**ix. Upper Little Sur Boy Scout**

- Camp should be closed during storm events in order to minimize potential risk to life.
- Because the Little Sur River is modeled as a “watch stream” a bulking factor to flow analysis should be considered when designing mitigations. It has been our experience that a bulking factor of 50 percent has been used in other post-fire responses.
- Follow recommendations provided in the BAER analysis of the camp access road.
- Follow recommendations regarding tree hazards (F.O. Consulting).

**x. Lower Little Sur**

- Conduct storm patrols of the bridge following storm events.
- Because the Little Sur River is modeled as a “watch stream” flood hazards analyses may be need to consider bulking factors to model the increase in runoff volume due to the contribution of sediment and debris

**xi. Big Sur River**

- Develop an early warning system.
- State Park campgrounds at Andrew Molera and Pfeiffer Big Sur State Parks within the 100 year FEMA flood zone should be closed during storm events.
- Because the Big Sur River is modeled as a “watch stream” a bulking factor to flow analysis should be considered when designing mitigations. The bulking factor should be used to estimate areas of potential flooding exceeding the FEMA 100-year flood zone. It has been our experience that a bulking factor of 50 percent has been used in other post-fire responses.


**Sediment Production (tons/acre)**

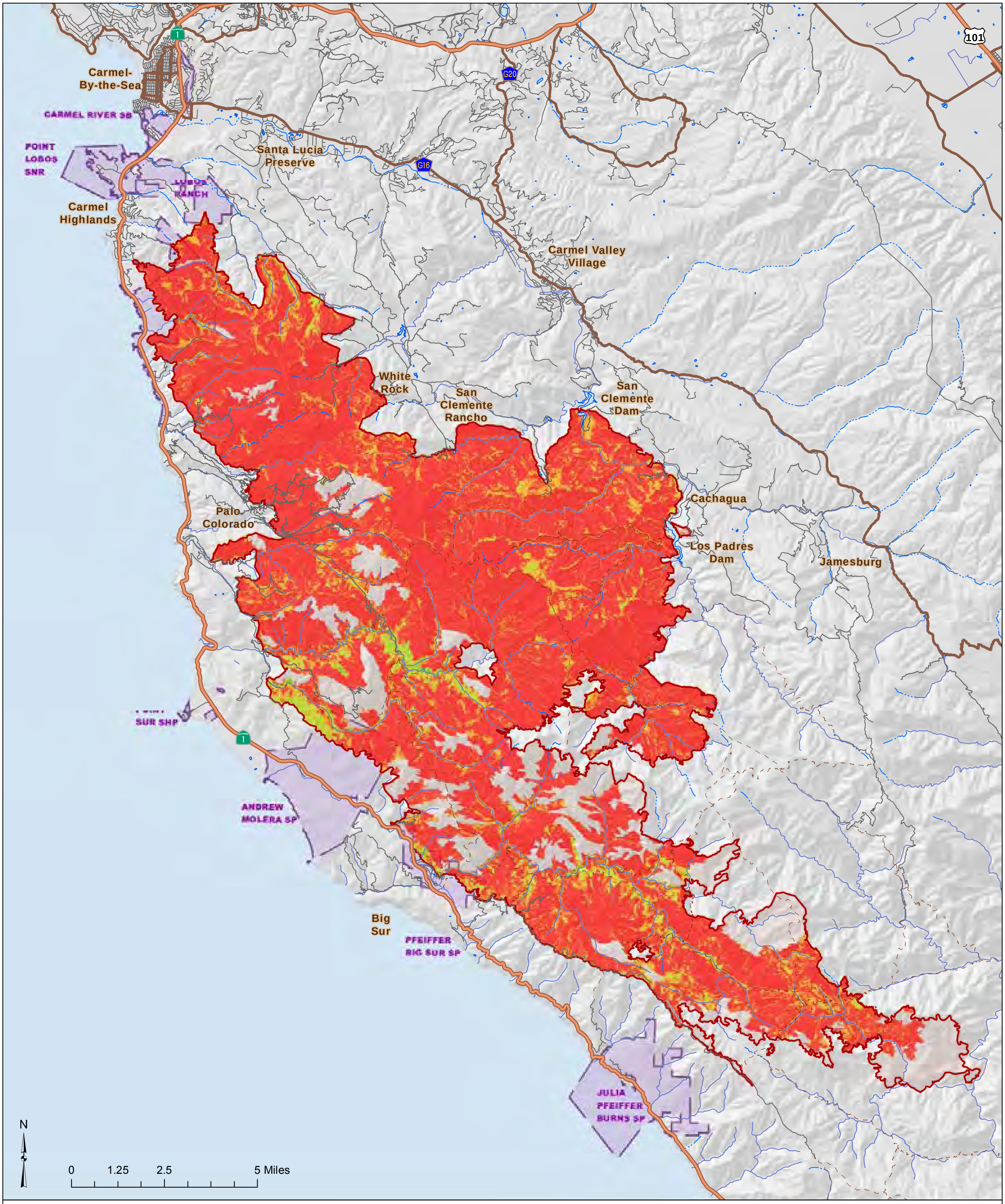
10-year storm event

0-5

>5

## Appendix E
## GeoWEPP Derived Surface Erosion
Soberanes Incident
CA-BEU-003422

Soberanes Incident
Monterey County
Perimeter from 2016/09/12




Erosion Hazard Rating

- Extreme
- High
- Low
- Moderate

# Appendix F
## Erosion Hazard Rating Map
Soberanes Incident
CA-BEU-003422

Soberanes Incident
Monterey County
Perimeter from 2016/09/12

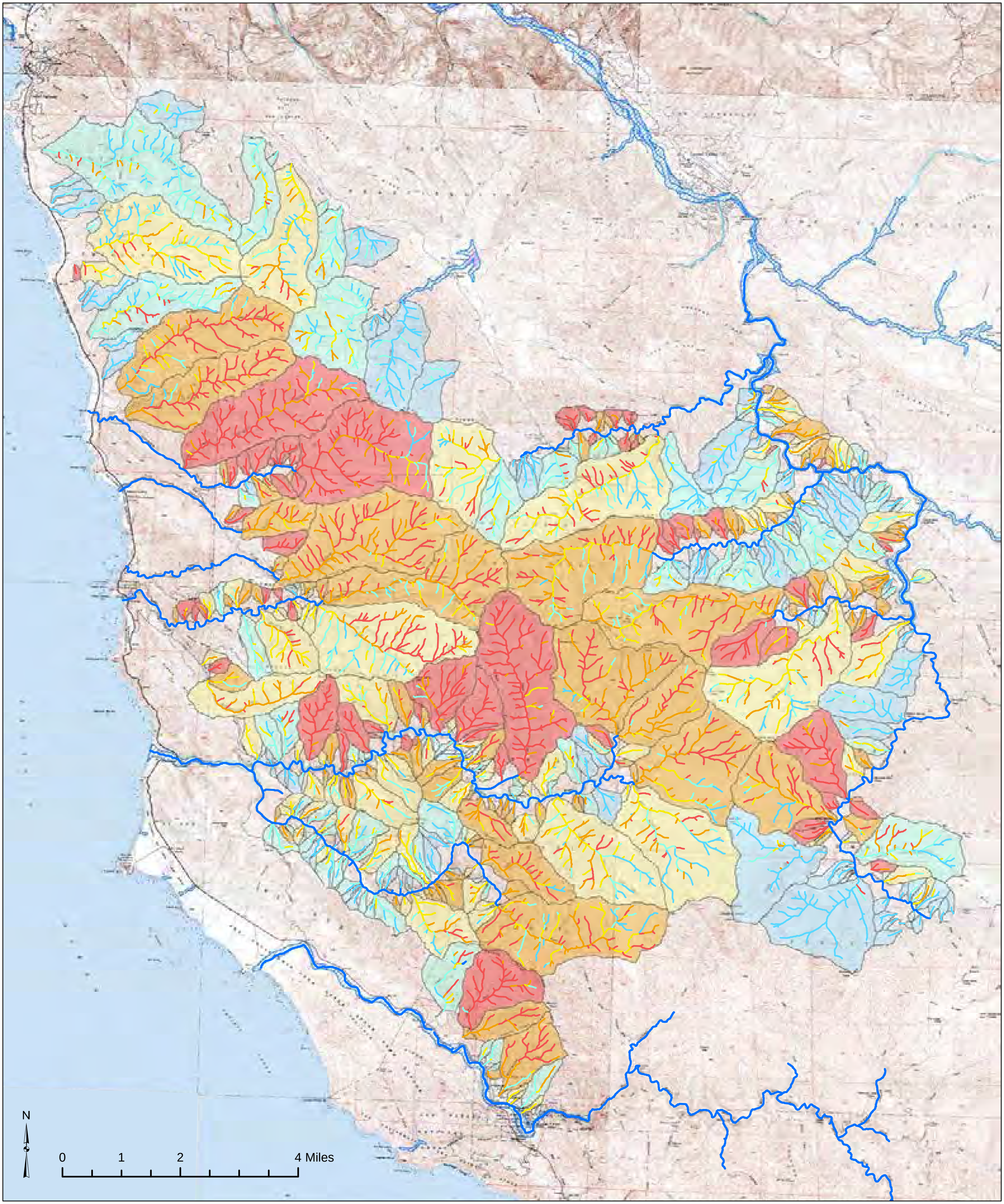
# Appendix G. Soberanes BAER Risk Matrix

| Soberanes BAER Risk Matrix | | | | |
|---|---|---|---|---|
| **VAR** | **Latitude** | **Longitude** | **Value at Risk** | **WERT Team Notes** |
| | | | | |
| 1 | 36°14'57.09"N | 121°46'44.21"W | Main stem of the Big Sur River and any issue with increased flow | Assessed, hazards noted |
| 2a | 36°15'3.15"N | 121°47'12.01"W | Big Sur Lodge culvert/parking lot | Assessed, hazards noted |
| 2b | 36°15'9.31"N | 121°47'3.73"W | Road/structures along Creek | Assessed, hazards noted |
| 3a | 36°15'51.09"N | 121°47'57.17"W | General HUC8 debris flow potential | Assessed, hazards noted |
| 3b | 36°15'56.19"N | 121°47'49.43"W | Debris flow potential and flooding impacts to structures | Assessed, hazards noted |
| 3c | 36°16'15.02"N | 121°48'14.75"W | Debris fow hazard and flooding potential to structures | Assessed, hazards noted |
| 4 | 36°19'55.81"N | 121°52'50.95"W | Mouth of Little Sur structures. El Sur Ranch road | Behind Lock gate, inaccessible no apparent structures |
| 5 | 36°19'51.14"N | 121°51'44.87"W | Green bridge on Old coast ridge road | Assessed, hazards noted |
| 6 | 36°19'56.66"N | 121°51'34.89"W | Structure in Little Sur? | Assessed, hazards noted |
| 7 | 36°19'58.29"N | 121°47'55.39"W | Boy Scout Camp | Assessed, hazards noted |
| 8 | 36°20'52.89"N | 121°48'29.67"W | Botchers Gap to Boy Scout camp road. FS maintained | Verified by BAER Team |
| 9 | 36°21'21.79"N | 121°48'45.44"W | Botchers Campground | Verified by BAER Team |
| 10a | 36°21'8.49"N | 121°52'35.69"W | Old Coast ridge road west of Green bridge | Assessed, hazards noted |
| 10b | 36°20'41.22"N | 121°51'54.83"W | Old coast road and private access road above | Assessed, hazards noted |
| 11 | 36°22'10.21"N | 121°53'38.11"W | Mouth of Bixby Creek development | Assessed, hazards noted |
| 12a | 36°22'38.11"N | 121°53'57.63"W | Structures in lower creek mouth north of Bixby | Not assessed behind locked gate, inaccessible - possible well |
| 12b | 36°22'41.33"N | 121°53'25.14"W | Possible structure in canyon n of Bixby | Not assessed behind locked gate, inaccessible - possible primative camsite |
| 13a | 36°22'40.29"N | 121°51'10.82"W | Palo Colorado road bridge | Assessed, hazards noted |
| 13b | 36°22'40.90"N | 121°51'18.38"W | Palo Colorado Road - dry ravel, plugged culvert, side channel, debris flow potential. This section has Mo. County maintenance | Assessed, hazards noted |
| 14 | 36°22'43.35"N | 121°51'17.22"W | Private drive above Palo Colorado | Assessed, hazards noted |
| 15a | 36°22'48.68"N | 121°51'39.87"W | Roads/homes in Palo Colorado. | Assessed, hazards noted |
| 15b | 36°22'54.33"N | 121°51'47.38"W | Palo Colorado Bridge | Assessed, hazards noted |
| 15c | 36°22'59.51"N | 121°51'53.84"W | Palo Colorado Bridge | Assessed, hazards noted |
| 15d | 36°23'23.56"N | 121°51'51.43"W | Roads/homes in Palo Colorado | Assessed, hazards noted |
| 15e | 36°23'23.38"N | 121°52'17.83"W | Palo Colorado bridge | Assessed, hazards noted |
| 15f | 36°23'29.49"N | 121°52'31.27"W | Roads/homes in Palo Colorado | Assessed, hazards noted |
| 16 | 36°24'6.65"N | 121°52'3.68"W | Private road and home in drainage N of Palo Colorado Road | Assessed, hazards noted |
| 17a | 36°24'54.79"N | 121°54'43.11"W | Garrapata Creek roads/structures | Assessed, hazards noted |
| 17b | 36°24'52.46"N | 121°54'12.43"W | Garrapata Creek roads/structures | Assessed, hazards noted |
| 17c | 36°24'59.89"N | 121°54'13.79"W | Garrapata Creek roads/structures | Assessed, hazards noted |
| 17d | 36°25'13.11"N | 121°53'35.43"W | Garrapata Creek roads/structures | Assessed, hazards noted |
| 17e | 36°25'33.46"N | 121°52'53.01"W | Garrapata Creek roads/structures | Assessed, hazards noted |
| 18a | 36°25'32.77"N | 121°54'46.13"W | Hwy 1 culverts/underpasses Caltrans examining many of these. Contact Caltrans | Caltrans Jurisdiction |
| 18b | 36°25'56.86"N | 121°55'3.05"W | Hwy 1 culverts | Caltrans Jurisdiction |
| 18c | 36°27'22.11"N | 121°55'26.18"W | Hwy1 | Assessed, hazards noted |
| 18d | 36°27'37.02"N | 121°55'29.34"W | Hwy1 culverts | Caltrans Jurisdiction |
| 18e | 36°27'40.75"N | 121°55'30.62"W | Hwy1 culverts | Caltrans Jurisdiction |
| 18f | 36°28'1.35"N | 121°55'45.09"W | Hwy 1 | Caltrans Jurisdiction |
| 18g | 36°28'15.88"N | 121°56'3.51"W | Hwy1 | Caltrans Jurisdiction |
| 18h | 36°28'40.97"N | 121°56'10.63"W | Hwy 1 | Caltrans Jurisdiction |
| 19 | 36°27'17.67"N | 121°55'20.21"W | Soberanes Cr. roads/structures | Discussed with State Parks - SP removing foot bridge |
| 20 | 36°28'37.89"N | 121°55'58.80"W | Creek crossing on pvt road | Assessed, no hazards noted |
| 21 | 36°28'42.66"N | 121°54'50.00"W | San Remo Road | Assessed, hazards noted |
| 22 | 36°29'23.52"N | 121°54'3.16"W | Roads/homes above Carmel highlands | Assessed, no hazards noted |
| 23 | 36°31'18.94"N | 121°55'27.38"W | San Jose Creek residence/roads | Assessed, hazards noted |
| 24 | 36°31'6.10"N | 121°54'40.19"W | San Jose Canyon Creek road | Assessed, no hazards noted |
| 25 | 36°29'20.14"N | 121°49'1.14"W | Carmel River/Sediment+flow issues | Assessed, hazards noted |
| 26a | 36°29'16.30"N | 121°45'16.42"W | Possible increased flow near Carmel Valley. Only a small portion of upper watershed burned. | Assessed, hazards noted |
| 26b | 36°29'28.41"N | 121°45'5.06"W | Possible increased flow near Carmel Valley. Only a small portion of upper watershed burned. | Assessed, hazards noted |
| 27 | 36°27'14.64"N | 121°48'25.39"W | San Carlos Summer Camp | Assessed, hazards noted |
| 28 | 36°27'31.05"N | 121°47'58.14"W | San Carlos reservoir | Assessed, no hazards noted |
| 29 | 36°24'42.31"N | 121°46'37.56"W | White Rock gun club road | Assessed, hazards noted |
| 30 | 36°24'40.43"N | 121°46'24.03"W | White Rock Lake | Assessed, no hazards noted |
| 31 | 36°25'14.00"N | 121°44'18.72"W | Dormody Road and structures | Assessed, hazards noted |
| 32 | 36°25'29.94"N | 121°43'40.56"W | Reservoir | Assessed, no hazards noted |
| 33 | 36°16'10.53"N | 121°48'26.58"W | Road/structures | Assessed, hazards noted |
| 34 | 36°23'6.05"N | 121°40'8.23"W | Los Padres Reservoir - sedimentation and increased water input | Assessed, no hazards noted |
| 35 | 36°26'9.09"N | 121°42'30.74"W | Water diversion and conveyance of San Clemente dam infrastructure | Assessed,no hazards noted |
| 36 | 37° 3'37.80"N | 121° 4'33.72"W | Water diversion and conveyance of San Luis dam infrastructure | N/A |
| other | | | Trout Farm road (1 main creek crossing at un-named creek in sec 20 near BM 3349) county | Assessed, no hazards noted |
| other | | | Botcher Gap Camp fencing FS | Forest Service |
| other | | | Aquatics species of Big Sur, Little Sur, and Carmel Rivers county | N/A |
| other | | | Sur areas Pvt | N/A |
| other | | | county | N/A |
| other | | | Loss of soil productivity in high to moderate SBS areas. Pvt & FS | N/A |
| other | | | Loss of soil due to OHV cross-country riding | N/A |

## Appendix H. List of Contacts

| NAME | AGENCY | E-MAIL | PHONE |
|---|---|---|---|
| Alec Arago | Rep. Farr's Office | Alec.arago@mail.house.gov | |
| **Andrew Madsen**, Public Affairs Officer | USFS, Los Padres NF | andrewmadsen@fs.fed.us | 805-961-5759 |
| **Anita Brown,** Public Affairs Specialist | USDA, NRCS | Anita.Brown@ca.usda.gov | 530-792-5644 |
| **Bobette Parson**, District Conservationist | USDA, NRCS | Bobette.parsons@ca.usda.gov | 831-424-1036 x101 |
| **Brandon Swanson** | Mo. Co. RMA (Resource Management Agency) | Swansonb@co.monterey.ca.us | 831-755-5334 |
| **Butch Kronlund** | CPOA | bpkronlund@aol.com | 831-667-0332 |
| **Consultant for CPOA Barry** | | Need contact info | |
| David Innis Environmental Scientist | Central Coast Regional Water Quality Control Board, | | 805-549-3150 |
| **Dick Bower** | Monterey County, Office of Emergency Services (OES) | bowerd@co.monterey.ca.us | 831-796-1902 |
| **Drew Coe** | CALFIRE Team Leader | drew.coe@fire.ca.gov | 916-217-4764 |
| Frank Ono Arborist | FO consulting | | 831-373-7086 |
| **Greg Norris**, Liaison for EWP | USDA, NRCS | Greg.Norris@ca.usda.gov | 530-792-5609 |
| **Jonathan Pangburn**, Unit Forester | CalFIRE | Jonathan.Pangburn@fire.ca.gov | 831-233-9475 |
| Judith Downing, BAER Team PIO | US Forest Service | jldowning@fs.fed.us | 530-908-5128 |
| John Hiles | State Parks Monterey District Maintenance Chief | | (831) 236-0556 |
| **Kathleen Lee** | Sup. Dave Potter | Leekm@co.monterey.ca.us | 831-578-0437 (cell) 831-647-7755 (work) |
| **Kay Joy Barge,** Asst. State Conservationist for Field Operations | USDA, NRCS | Kay.joybarge@ca.usda.gov | 831-424-1036 x131 |
| **Ken Ekelund** | CPOA, main contact | alec.arago@mail.house.gov | 831-915-6652 |
| **Ken Heffner**, Dep. Forest Supervisor | USFS, Los Padres NF | Kheffner01@fs.fed.us | 805-689-8137 |
| **Kevin Cooper**, Forest Biologist | USFS, Los Padres NF | kccooper@fs.fed.us | 805-680-0318 |
| **Luis Laracuente**, Emergency Watershed Protection Program Leader | USDA, NRCS | luis.laracuente@ca.usda.gov | 530-792-5622 |

| | | | |
|---|---|---|---|
| (EWP) | | | |
| **Maia Carroll, Monterey Co. PIO** | Monterey County PIO | carrollm@co.monterey.ca.us | 831-682-5958 |
| **Mark Moehling** | USDA, NRCS | Mark.moehling@ca.usda.gov | 831-424-1036 x122 |
| Michael Barnhart, 408-327-7009 Purpose | Environmental Manager Granite Construction, | | 408-327-7009 |
| Michael Wilson | BOY SCOUTS OF AMERICA Silicon Valley Monterey Bay Council #55 | | 408-410-8314 |
| **Monterey County Public Information Officer** | | carrollm@co.monterey.ca.us | |
| **Nathan Rezeau, Agency Administrator** | U.S. Forest Service | nrezeau@fs.fed.us | 805-925-9538 |
| **Paula Martinez,** Incident PIO | Soberanes Fire | Pio1fire@gmail.com | 831-320-2337 (personal cell) |
| **Rich Casale**, Primary BAER Contact | USDA, NRCS | Richard.Casale@ca.usda.gov | 831-475-1967 x101 |
| **Robert Baird**, Forest Supervisor | USFS-Los Padres NF | babaird@fs.fed.us | 202-205-0888 |
| Ryan Turner P.E., G.E., | California Department of Transportation | | (805) 549-3750 Office |
| **Sherrie Collins** | Monterey County, Office of Emergency Services (OES) | collinssl@co.monterey.ca.us | 831-320-7373 |
| **SoberanesFire,2016**-- Public Information Section | | SoberanesFire2016@gmail.com | |
| **Tim Short**, Monterey District Ranger | USFS, Los Padres NF | tshort@fs.fed.us | 831-206-2129 |
| **Tom Moss,** Senior Water Resources Hydrologist | Mo. Co. RMA (Resource Management Agency) | mosst@co.monterey.ca.us | 831-755-5847 |
| **Mark Strudley, PhD** National Weather Service | San Francisco/Monterey Bay Area | | 831-656-1710, x228 |
| **Dennis Staley** US Geological Survey | Geologic Hazards Science Center | | 303-273-8568 |
| Tom Paulino | Sen. Feinsten's Office | Tom_Paulino@feinstein.senate.gov | |

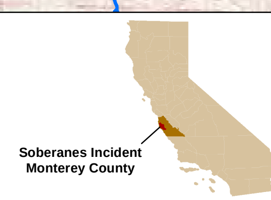



USGS Model Watch Stream
DWR Awareness Floodplain
FEMA Special Flood Hazard Area

Debris Flow Probablility
15 min, 28 mmh

| | |
|---|---|
| 0-20% | 0-20% |
| 20-40% | 20-40% |
| 40-60% | 40-60% |
| 60-80% | 60-80% |
| 80-100% | 80-100% |

**Appendix I**
**Debris Flow Probability, 28 mmh**
**Soberanes Incident**
**CA-BEU-003422**



Cleveland, G.B., 1973, Fire + Rain = Mudflows:
California Geology, Volume 26, Number 6, pp. 127-135.

# FIRE + RAIN = MUDFLOWS

# BIG SUR

# 1972

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Rainwater rushes down barren hillslopes, converges in narrow canyons, and bursts out onto broad valley floors that contain the main conduits along which streams flow to lower elevation. The water slices through brush and timber, increasing in density as it picks up loose soil, and plant and rock fragments along the drainage courses. At times it may slow, piling up against natural dams of debris or riding up onto projecting hillslopes. But when unopposed, it gathers speed and sound — the debris fragments clack and rumble as they are beaten together in the churning flow. The muddy train may slam into a community, pluck cars from the roads, ooze around houses and punch through windows, spilling destruction within. Eventually it slows and stops, its energy mostly dissipated in the ruin created along its path. This is a mudflow.

Although mudflows occur over wide areas of California each year, most of them slip by unnoticed. Only when they block a road or sail through a living room is much attention given to anything as mundane as mud. Yet mudflows are potentially more dangerous than other types of landslides because they can form with dramatic suddenness and move, at times, with astonishing velocity. Some have been clocked at over 50 miles per hour.[4] Because of their greater density, mudflows have a relatively higher destructive capability than do floodwaters, and, unlike flood waters, the mud doesn't recede after a storm has passed but may become a relatively permanent feature of the landscape.

A mudflow is more than just mud that flows. Fine grained particles usually make up the largest percentage of the solid material, but the balance can be all manner of rock fragments and plant debris. It is the fine grained component of the mix, however, that gives the flow its mobility. Each grain or aggregate of grains is encased in a film of water which insulates it from any hard knocks by its neighbors. This leads to reduced friction and increased mobility. Mixtures with the highest ratio of solid to liquid may move so slowly as to be classified as creep or slope wash deposits. As the amount of water increases the material may begin to slide as a discrete unit along a defined slip plane; this type of slope failure is called a mudslide or an earthslide. The mudflow phase is reached when the water content is sufficient for the mass to actually flow. Depending upon the nature of the solid material, the amount of water can range from 10 to 60 percent. As the ratio of solids to water changes, the density and viscosity change, and depending upon the gradient of the slope, the velocity and carrying capacity change as well. Relatively dense mudflows, some of which reach a density nearly two and a half times that of water, can support and transport exceptionally large rocks. One mudflow 4 feet thick transported a rock 9 by 11 by 16 feet; thicker flows have moved blocks 20 by 30 by 40 feet.[4] If the rock debris in the flow is mainly coarse fragments, such as cobbles and boulders, it may be called a debrisflow. Depending upon the volume and properties of a mudflow, the gradient of the slope, and the topography, mudflows can travel a few feet to tens of miles. In 1941 a mudflow at Wrightwood, in the San Gabriel Mountains near Los Angeles traveled about 15 miles.[16] Mudflows, the product of the amount of solid material and water available at any one site, may range widely in volume from a few cubic yards to millions of cubic yards. The mudflows at Wrightwood originate from a debris source estimated at 18 million cubic yards and individual flows have exceeded a million cubic yards.[14]

Mudflows may be associated with volcanic eruptions when great volumes of water from melting snow fields and glaciers or steam derived from the volcanic vent are introduced rapidly into poorly consolidated deposits of volcanic ash or other volcanic debris. But most frequently mudflows occur during intense rainfall. In climatic zones where the rainfall is frequently intense, there are two places where mudflows commonly originate: at the bases of steep slopes, and at the mouths of major canyons. During periods of normal stream flow it is at these locations, where stream gradients become gentle, that weathered rock and soil tend to accumulate. After they become saturated, these thick blankets of debris become the main source materials for mudflows when sufficient stream energy becomes available to move them.

# MUDFLOWS AT BIG SUR

Take one burned over forest slope, add intense rainfall, and stand back — instant mudflow. This recipe is well known and the events are predictable, yet precise causes of the mudflow phenomenon are not well understood. One example of mudflow evolution occurred recently at Big Sur, Monterey County, California, when nearby hills and canyons shed their skin of loose debris during a series of early season rainstorms. The geographic setting and the nature and sequence of events at Big Sur illustrate some of the conditions that can lead to the development of mudflows.

## The Setting

The sea, the mountains, and the forest dominate the Big Sur coast. Even its thousands of visitors, and those who live scattered along the lower reaches of the Big Sur River or adhering to the steep hillslopes facing the sea, are lost in significance in comparison with the greater dimension of the natural setting.

The Sur fault intercepts the Big Sur River as it flows westward out of the higher reaches of the Santa Lucia Range (see map). The river then trends northwest and follows the fault zone, cutting a sinuous defile in the more easily eroded rocks of the fault zone before it empties into the sea near Point Sur. Along this 5 mile stretch of the river is the Big Sur area. In contrast to the more gentle slopes and lower elevations on the southwest of the fault zone, to the northeast, Big Sur is crowded against a mountain front which rises abruptly to more than 3500 feet. Slope angles range from about 15 degrees to 90 degrees with most slopes between 25 and 40 degrees.[10] Off this rock wall flow several minor tributaries to the Big Sur River, and on three of these tributaries damaging mudflows originated in 1972.

The Sur fault zone separates the dissimilar rocks of the ancient Sur Series on the northeast, from the younger Franciscian Formation on the southwest.[12] The Sur Series in this area is comprised of hard metamorphic rocks, largely gneiss, quartzite, and limestone; the rocks of the Franciscian Formation are mainly sandstone and shale. A narrow belt of fine- to coarse-grained sandstones, and

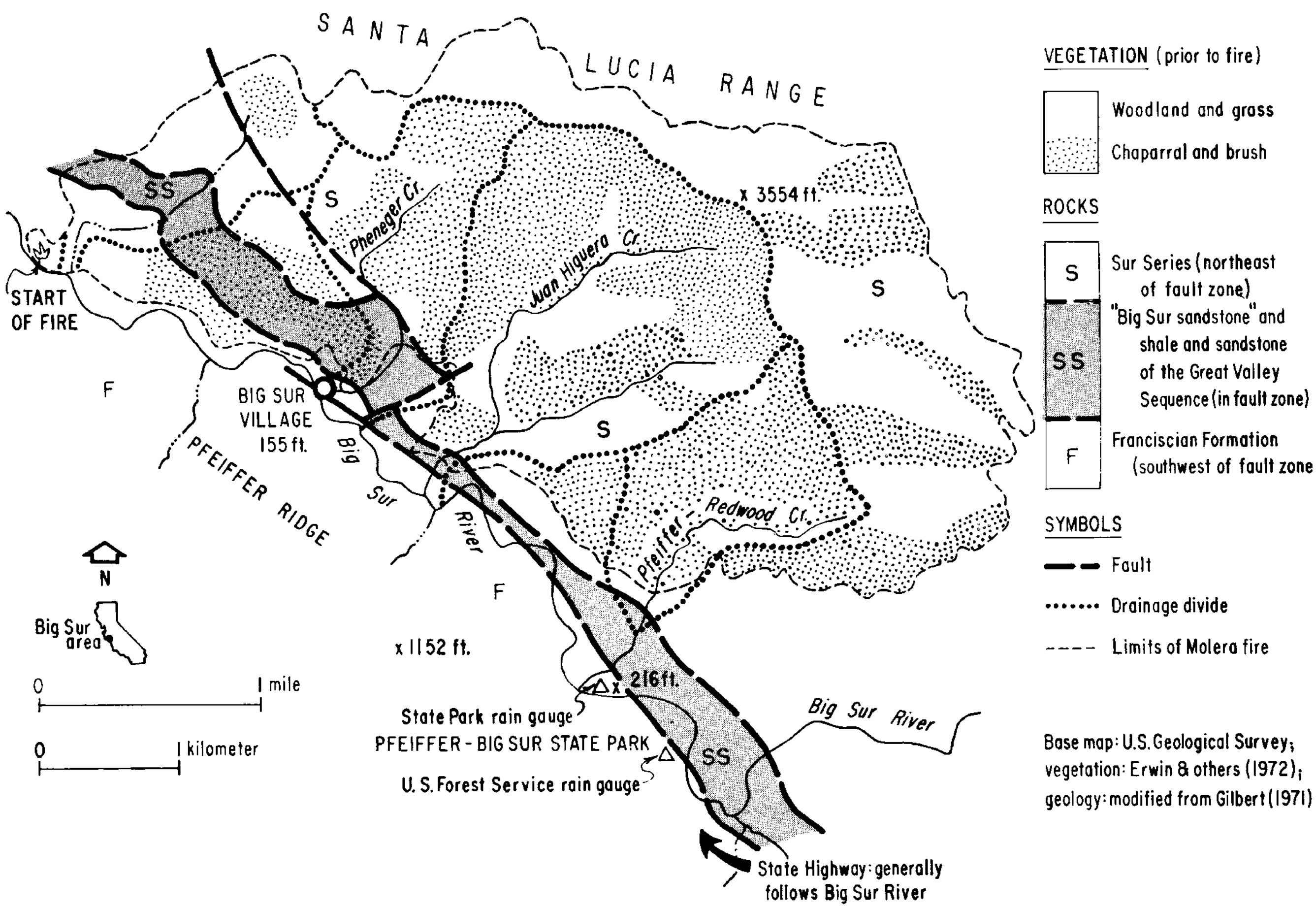


Figure 1. Geologic and geographic sketch map of Big Sur area, California.

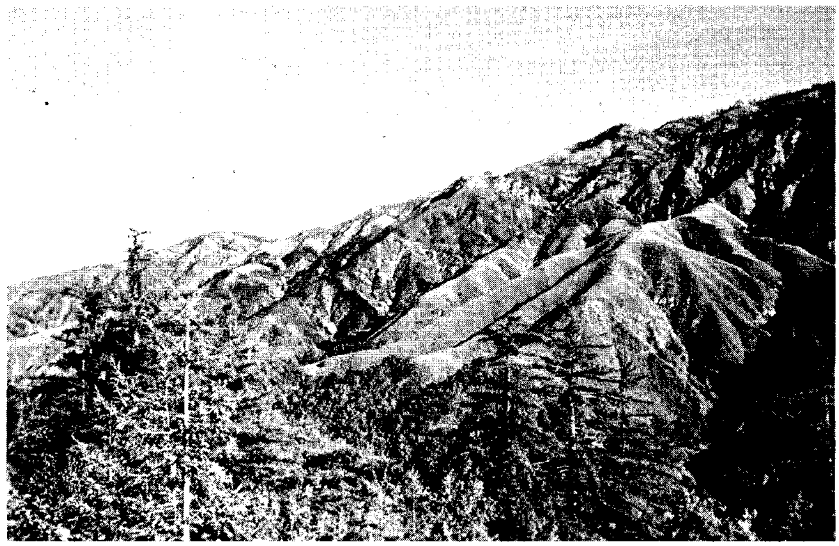

Figure 2. Molera fire which occurred in early August 1972 left baked slopes above Big Sur. View north.

conglomerate and shale is sandwiched between the other two rock units and forms the core of the fault zone. The rocks in the fault zone are part of the Great Valley Sequence and the "Big Sur Sandstone" (see map).[12] They form a weak foundation along the base of the hillslopes northeast of the Big Sur River and are more easily weathered and eroded than those of the Sur Series that are stacked above them. The weathered debris from the Great Valley Sequence and the "Big Sur Sandstone" is mainly sand and clay; debris from the Sur Series is coarse angular blocks of gneiss. These and other rock materials have been classified into several soil types.[10] The soil types are all generally similar — coarse grained, shallow, and moderately erodable. Erosion rates vary widely, however, and depend upon local conditions within each drainage basin. The thin soil cover and the impermeable bedrock below leads to rapid runoff.

Big Sur, lying near sea level, receives about 40 inches of rainfall annually giving it a somewhat humid climate and a vegetation cover to match.[6] Higher elevations nearby drain toward Big Sur and receive an annual rainfall of from 50 to 60 inches.[10] But these annual rainfall figures reveal little with respect to the extremes of weather, especially in terms of rates of rainfall and runoff.

Both short and long duration rainfall totals are related to the landslide process, but short duration high intensity rainfall appears to be most closely related to mudflow activity. Less intense rainfall of longer duration mainly influences massive soil and bedrock landslides.

The rainfall intensity figures for the Big Sur area, when compared with those from other parts of California, show that short term rainfall is relatively high in the Big Sur region. Rainfall commonly will reach intensities equivalent to 0.8 inches per hour. Much higher rates per hour are reached for shorter durations.[17] Only local areas in the Transverse Ranges in the southern part of the state, and the Santa Cruz Mountains to the north, can normally expect slightly higher *intensity* rainfall than that of coastal Monterey and San Luis Obispo Counties.

In contrast to both intensity and total annual rainfall, single-storm rainfall totals around Big Sur are generally lower than single-storm totals for most of the rest of the California coast. But compared to many interior parts of the state and for the western states generally, storm totals in the Big Sur region are significantly higher.[13]

The Big Sur River drains a relatively small region of about 46 square miles, but storm rainfall totals within the region vary widely. It is common for the lower reaches of the river to flood. Weather records indicate that the Big Sur River drainage basin has a mean annual rainfall of about 51 inches, of which roughly half runs off. This amounts to a mean runoff of about 63,000 acre-feet. During 7 non-consecutive years of severe storms and resultant flooding between 1931 and 1960, runoff was very high, reaching a high of 177,500 acre-feet in 1941. The lowest runoff was in 1931 when only 8100 acre-feet were recorded.[1] Thus, it may be inferred that the capacity of the stream courses will not accommodate the runoff without flooding during peak years of high rainfall.

The influence of rainfall on the formation of mudflows is dependent upon other conditions as well. The character and density of the vegetation has a profound influence on regulating the way in which the rainfall is dissipated. The plants prevent the falling raindrops from hitting the soil at a high velocity, allowing a greater amount of the moisture to enter the soil rather than to run off over the surface and erode away the soil. Once the moisture is absorbed by the soil, part of it is taken up by the plant which returns most of it to the atmosphere by transpiration. Plants also impart strength to the soil through their interlocking roots which help to prevent the soil from moving down slope. Other conditions being the same, this root mat tends to allow steeper slopes to be maintained than where the vegetation is either more sparse or absent. The influence of the vegetation is further dependent upon the kinds of plants represented. Different plant types, because of their physiology, will utilize and dissipate the ground moisture in various ways. The nature of their root structure also will bear on the gross strength of the soil.

In the Big Sur area the slopes are mantled mainly with chaparral and grass, but stands of timber grow locally in the canyon bottoms. Chaparral is a collective term for a group of similar shrubs and small trees which make up the dull, grayish green, velvet-like cover on much of the coastal ranges of California. The composition of the chaparral community is not everywhere the same, but changes in concert with local soil and climatic conditions. At Big Sur it is composed of coast live oak, laurel, tan oak, chamise, ceanothus, toyon, and manzanita among other plants. Trees in the canyon bottoms are the coast redwood, sycamore, madrone, cottonwood, maple, alder, and willow. Chaparral comprises about 65 percent of the plant cover with trees and grass comprising the remainder in about equal amounts.[10]

## The Events

If the vegetation did not normally insulate the steep slopes from the effects of winter rainfall, the mountains above Big Sur would regularly shed torrential amounts of runoff. Even the vegetative cover is not always sufficient to completely offset periodic high intensity rainfall.

### Molera Fire

On 1 August 1972, the tenuous equilibrium between the rainfall and the vegetation, soil, and slope that existed on the mountainsides was almost completely destroyed when a wildfire developed west of Highway 1, north of Big Sur Village. It swept northeastward to the crest of the main ridge above Big Sur and southward along the east side of Big Sur Canyon. It was contained at a cost of about $850,000 on 6 August after burning 4300 acres of chaparral, grass, and timber (figures 1 and 2).[10] The natural beauty of the canyon floor with its vegetation escaped destruction, but it lay below a baked and largely disrobed landscape to the east. The fire burned through four basins tributary to and northeast of the lower Big Sur River — Pfeiffer-Redwood Creek, which flows through the State Park, Juan Higuera Creek, Pheneger Creek, and an unnamed creek a mile northwest of Big Sur Village.

The intensity of the heat from the fire, especially where it was fueled by dense thickets of low growing chaparral, baked the surface of the soil to a bright red and brown crust. Trees burned vigorously in some side canyons, but elsewhere they were left only slightly charred with their leaves prematurely turned to autumn colors.

### Rain

Next came the rain. In a series of storms beginning in mid-October and lasting for several days, and then again in mid-November (tables 1 and 2); both storm periods brought flooding and mudflow activity. The second period was the more destructive.

The first storm yielded 5.07 inches of rain from 10 October through 17 October. The major drainages were flooded during this period, but mudflows occurred only on 12 and 15 October, during intense, short duration rainfall. The mudflow on 12 October followed 0.82 inches of rain, most of which fell within an hour; that on 15 October followed rainfall of 0.73 inches, which was recorded between 0800 and 0900 of that day.

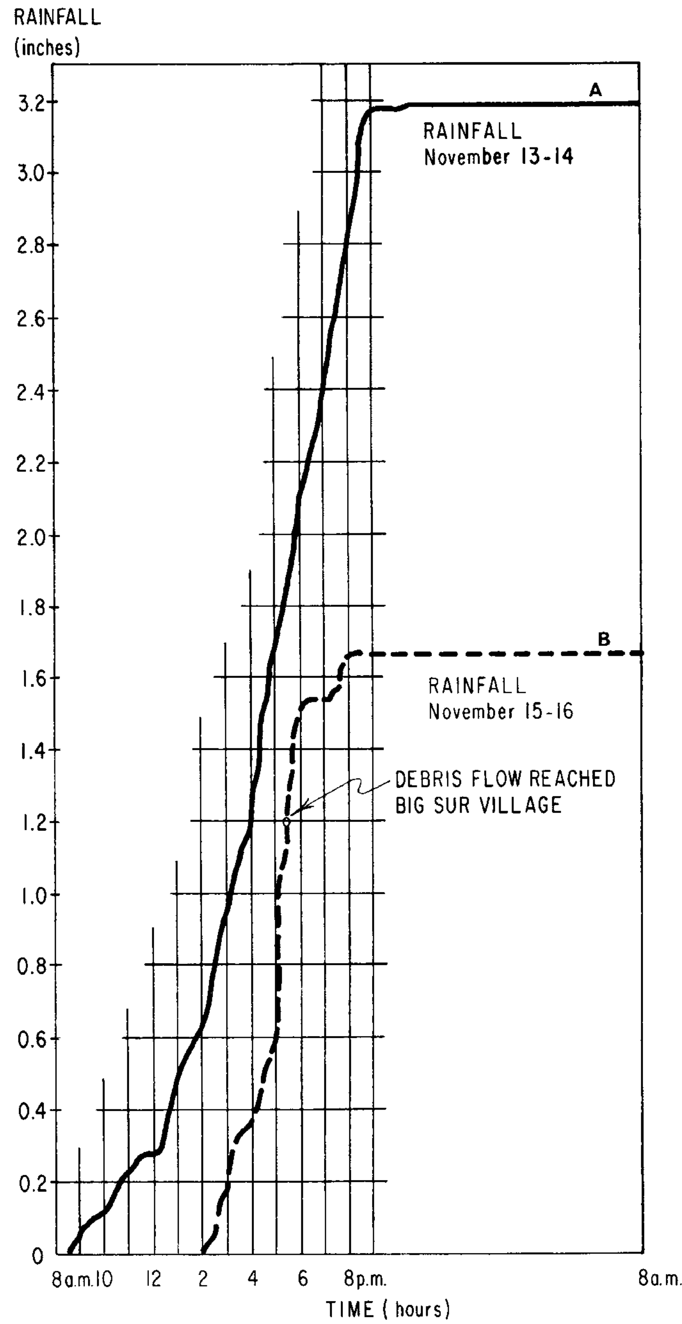


Figure 3. Graph showing the cumulative rainfall for 13-14; 15-16 November at Big Sur, California, as measured by a recording rain gauge. The total rain fall shown does not represent the total amount of rain for the 24 hour period. See Table 2 for correct totals. Differences are caused by the inaccuracies introduced by the recording rain gauge apparatus. The accuracy of this apparatus decreases with increased rainfall. *Courtesy of U.S. Forest Service weather station, Big Sur.*

## TABLE 1: RAINFALL, OCTOBER STORM, BIG SUR, CALIFORNIA - 1972

Weather station at Pfeiffer-Big Sur State Park; rainfall recorded daily at 0800 for previous 24 hour period.

| Date | Rainfall | Remarks |
|---|---|---|
| Prior to 10 October | 0.18 inches | |
| 10 October | 0.32 | |
| 11 | 0.01 | |
| 12 | 0.82 | Most fell during a short period around 0700. |
| 13 | 0.05 | |
| 14 | 0.93 | |
| 15 | 1.02 | 0.73 inches fell between 0800 and 0900. |
| 16 | 0.82 | |
| 17 | 1.10 | |
| Storm total | 5.07 inches | |

Data from: California Department of Parks and Recreation, Pfeiffer-Big Sur State Park

The rainfall during the November storm was measured on a continuous recording rain gauge installed after the October storm by the U.S. Forest Service. This record gives more precise data in terms of critical rates of rainfall and the beginning of the mudflows, although it less accurately records total amount of rainfall. Figure 3, curve A shows the rate of rainfall for the 24 hour period between 0800 hours 13 November and 0800 14 November. Although total rainfall was high (4.98 inches as measured by standard, non-recording, cumulative rainfall gauge), the short term hourly rate was not as great as for the period 15-16 November when a 24-hour total of 1.79 inches fell (figure 3, curve B). The 13-14 November curve shows a steady heavy rainfall beginning at 0830 and ending about 2100; no mudflows reached Big Sur during this period. The curve for 15-16 November indicates heavy rainfall began in the early afternoon and reached its highest intensity beginning at 1700 when 0.44 inches fell in 15 minutes. After this surge, it took another 15 minutes for the runoff to accumulate and mix with debris and race down Pheneger Creek, for at 1730 on 15 November a debris flow, estimated at several thousand cubic yards, struck Big Sur Village.

The rain gauges were not in the drainage basins from which the mudflows originated, but were along the Big Sur River. Furthermore, because of the high mountains to the northeast, rainfall intensities at higher elevations may have been significantly greater. Stream flow measurements would be more meaningful if they were available.

## TABLE 2: RAINFALL, NOVEMBER STORM, BIG SUR, CALIFORNIA - 1972

Weather station at Pfeiffer-Big Sur State Park and U.S. Forest Service, Big Sur; rainfall recorded daily at 0800 for previous 24 hour period at both locations.

| Date | Rainfall | | | Remarks |
|---|---|---|---|---|
| | State Park | Forest Service | Recording Gauge | |
| 10 November | 0.88 inches | 0.80 inches | | |
| 11 | 1.27 | 1.15 | | |
| 12 | 0.28 | 0.27 | | |
| 13 | tr | 0.0 | | |
| 14 | 4.70 | 4.98 | 3.18 | Flooding only on 13-14 November |
| 15 | 2.47 | 2.38 | 1.65 | Destructive debris flow occurred at 1730 15 Nov. after 0.44 inches of rain fell in 15 minutes |
| 16 | 1.83 | 1.79 | | |
| 17 | 0.15 | —— | | |
| 18 | 0.01 | — | | |
| Storm total | 11.59 inches | | | |

Data From: California Department of Parks and Recreation, Pfeiffer-Big Sur State Park; and U.S. Forest Service, Big Sur

Figure 4. Mudflows repeatedly closed Highway 1 at Pfeiffer-Big Sur State Park during storms of October and November 1972. Mudflows jumped the bed of Pfeiffer-Redwood Creek and crossed the highway to the Big Sur River (out of sight to the right). View southeast.

## Mudflows

During the storm periods of late 1972 three of the four creeks draining into the Big Sur River at Big Sur would at one time yield relatively clear water and at another time a mudflow or debris flow. Generally, Pfeiffer-Redwood Creek carried fine grained materials and only mudflows occurred along this drainage course (figure 4). The size of the debris fragments was greater on the creeks to the north and at Pheneger Creek, blocks of rock 8 feet in greatest dimension and trees 4 feet in diameter were carried along, within, or riding atop the flows (figure 5). Juan Higuera Creek carried relatively smaller volume mudflows than did the other two creeks.

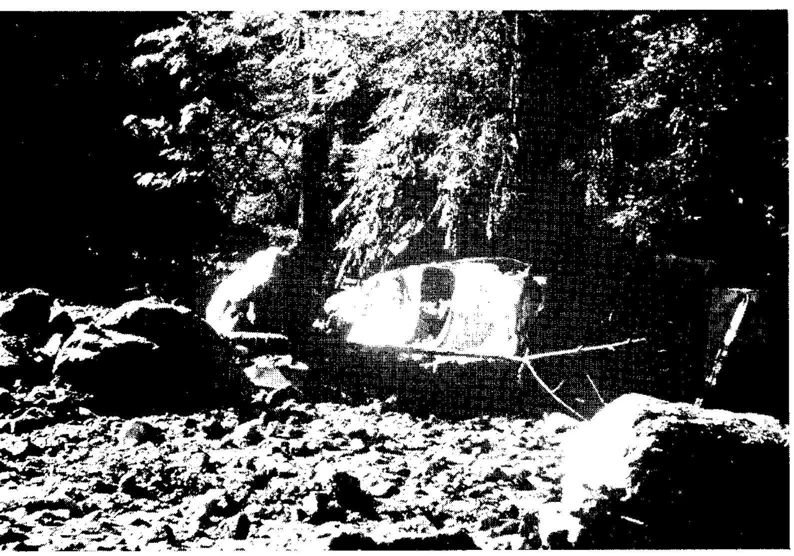

Figure 5. Large boulders, some 8 feet in greatest dimension, rode atop the debris flow that struck Big Sur Village on 15 November, 1972. Debris shown here came to rest in the Post Office parking lot. An automobile was crushed between a large boulder and a tree. Fifteen other vehicles met a similar fate and four were known to have been washed into the Big Sur River.

The notable difference in grain size between the flows that originated on Pfeiffer-Redwood Creek and those farther north is difficult to explain; compare figures 4 and 5. The available source materials for all the flows is debris that accumulates near the mouths of the tributaries to the Big Sur River and the blanket of soil that mantles the hillslopes. These materials are derived from the face of the massif behind Big Sur which is mainly crystalline rocks and younger sedimentary rocks. The sedimentary rocks are of the Great Valley Sequence north of the cross fault near Pheneger Creek, and "Big Sur Sandstone", to the south. Although both units are mainly sandstones, some shale occurs with sand in the section to the south. This difference in lithology, the erosion of soil left unprotected after the fire, or the possibility that Pfeiffer-Redwood Creek failed to develop enough energy to move larger clasts, may account for the finer grained flows along this creek.

The volume of some of the flows was estimated to be on the order of 10,000 cubic yards. The estimates were difficult to make because succeeding flows overrode previously deposited flows, masking their original dimensions. Moreover, the ratio of solids to liquid ranged widely and after a flow stablized it "deflated" as the water drained away.

Some of the flows apparently moved at high velocity and generally in one or a few distinct pulses. Although no estimates are available, eyewitnesses could hear the flows approaching and were forced to run from their paths. Probably these flows traveled a few tens of miles per hour. The mudflow at the State Park on 12 October, however, moved relatively more slowly judging from the observations of State Park personnel. They noted that this flow moved about half a mile in 10 minutes, or about 3 miles per hour.

The mudflows and debris flows reached the inhabited sections of Big Sur several times during the October and November storms. The state highway was blocked by flows

Figure 6. Debris flow of 15 November 1972 inundated the Big Sur Village, damaged buildings, and swept vehicles ahead of it toward the Big Sur River, beyond the trees.

and numerous homes and business buildings were inundated by mud and water. The most devastating events occurred when the flows were diverted by previously deposited debris or when they jumped the drainage channels and moved into habited areas along unexpected routes.

On 15 November a debris flow was crowded out of the channel of Pheneger Creek at Big Sur Village and flowed toward the north and west cutting across the business area to the Big Sur River. It blocked the highway with a train of debris 6 feet thick, plowed through a cement block building, climbed up and around the lower story of the two story building that houses the post office, and farther beyond dropped a tow truck onto a house trailer. In all it smashed a dozen cars or more into trees and rocks and into each other, then rafted four of them to the river where one of them was washed downstream 2 miles from the village (figures 6 and 7).

Of the numerous ways in which mudflows originate, those associated with the "fire-flood sequence" have been studied in most detail. Although much remains to be learned, one of the most notable aspects of the events at Big Sur, is that they were predicted with uncanny accuracy well before they took place. A team of hydrologists, foresters, and pedologists, from the U.S. Forest Service, the U.S. Soil Conservation Service, and the California Division of Forestry, began an investigation of the area after the August 1972 fire and prepared a Forest Service report that gives a detailed chronology of what was to come.[10] Their conclusions were reached by measuring how the bedrock, soil, vegetation, and slope would react to expected weather conditions based on the climatic pattern of the region. From these data estimates were made of the amounts of debris available for transport by the stream, erosion and runoff rates, and what remedial measures could be taken to reduce the danger from flooding and mudflows.


Figure 7. Ironically, this establishment at Big Sur Village lived up to its name when some of the flow from Pheneger Creek chose to cut through a parking lot on its way to the Big Sur River.

## The Reasons

The cause of the mudflows at Big Sur may be traced to properties of the rocks and soils, and to the pattern of the rainfall during short time periods. The evidence suggests that the changes brought on by the fire set the stage for later mudflow and debris flow events.

During the October storm when mudflows were occurring at Big Sur, no other drainage courses from Big Sur south to the San Luis Obispo County line showed either mudflow activity or excessive runoff at the shoreline, even though rainfall appeared to be general all along the coast.

Three drainage basins within the fire area yielded mud—or debris flows—the fourth only flooded. Mudflow activity or flooding was not observed in drainage basins in which the vegetation was unaffected by the fire, even though the unburned basins lay adjacent to the fire zone. Moreover, as far back as 1910, local residents cannot recall any large mudflows, although the Big Sur area has been flooded several times during that period.

The already steep and largely impervious slopes were probably modified by the fire through changes in the physical and chemical regimen of the soil at, and just below, the ground surface. This could have occurred when the protective canopy of vegetation was destroyed and certain organic compounds were redistributed in the soil.

The loss of the plant cover exposes the ground to direct impact of the raindrops which reduces the infiltration capacity and increases runoff.[9] Without the plants to intercept the rainfall, the soil absorbs a smaller amount of moisture. The rainfall does not collect and run off along established depressions on the slope, but is dissipated rapidly as sheet flow.

Some evidence suggests that another mechanism may have conditioned the ground surface and increased the run off at Big Sur. After a heavy rainfall during the October storm period, members of the U.S. Forest Service examined the slopes above Big Sur in the fire area. The ground surface was moist, but by kicking into the soil a dry zone a few inches below the surface was uncovered. This indicated that, at least locally, a recently recognized phenomenon known as non-wettable or hydrophobic soil may have developed.[8] Hydrophobic soils are a particular product of fires in chaparral terrain.

Under a chaparral cover ammonium hydroxide and other organically derived compounds accumulate in the soil. These compounds contribute to the hydrophobic character of the soil. They are more concentrated below plants such as chamise (*Adenostoma fasciculatum*), but they also occur below other plants of the chaparral community: mountain mahogany, scrub oak and certain species of *Ceanothus*, among others.[8] When these plants burn, intense heat is generated. Above the ground surface, the temperature can reach 2000 degrees Fahrenheit. At the ground surface it can reach 1200 degrees, but because of the low heat conductivity of soil, the temperature drops off to 350 to 550 degrees F about 2 inches below the soil surface.

Laboratory experiments indicate that at high temperatures hydrophobic compounds are vaporized and part of the vapor condenses in a zone of concentration a few inches below the ground surface, forming an impervious layer. In these experiments, slightly non-wettable soils were heated above 400 degrees F for 5 to 20 minutes whereupon their hydrophobic properties increased, but when the temperature reached 800 to 900 degrees F, the hydrophobicity was destroyed.[7]

The implications of these relationships with regard to the origin of mudflows are far reaching. If a slope is burned over by a fire of intense heat, the near surface zone is purged of hydrophobic compounds. The vaporized compounds condense in a cooler zone just below the surface. Rainfall could then penetrate the surface layer and reduce its shear strength. Any excess water would migrate downslope, just above the impervious layer, carrying away the weakened material as a mudflow. All or part of this mechanism may have been important in forming the mudflows at Big Sur.

With the physical properties of the ground favoring rapid run off, the prolonged, and at times, high intensity rainfall of October and November reached critical levels with respect to debris transport. On some days, steady rainfall of relatively high total volume, apparently drained over or through the debris stored in the stream courses without much of the debris being transported (tables 1 and 2). The principal mudflow and debris flow activity occurred during or just after short periods of intense precipitation following a previous longer period of relatively steady, but not intense rainfall. The periods of intense rainfall yielded a volume of water flow that could not filter through the debris fast enough to be dissipated simply as flood water.

Because of the range of conditions that control runoff and subsequent debris transport in each of the drainage basins, no quantitative measure of rainfall intensity can be cited as being critical with respect to the formation of mudflows. Mudflows followed periods of rainfall with intensities of about 0.82 inches per hour, 0.73 inches per hour, and the destructive mudflow after 0.70 inches per hour.

Table 3 shows average hourly rates of rainfall of similar nature for the time periods on the curves in figure 3. Average hourly rates for the two total rainfall periods are comparable, but the high intensity of the rainfall on 15 November was nearly three times the intensity of the rainfall on 13 November, even though it was of much shorter duration. The highest intensity rainfall on 15 November, just prior to the major mudslide, lasted for only 15 minutes. No quarter hour intensity rates on 13 November even came close to the intensity recorded on 15 November. These data suggest that mudflow activity may depend less on total daily rainfall and more on relatively higher hourly rates followed by shorter bursts of precipitation. But antecedent rainfall of several hours or days undoubtedly primes the terrane in terms of lowering its infiltration capacity by saturating the ground. Thus, less of any subsequent short duration, higher intensity rainfall infiltrates into the ground, leading to greater rates of runoff and subsequent mudflow activity.

TABLE 3: AVERAGE HOURLY RAINFALL INTENSITY
NOVEMBER STORM, 1972, U.S. FOREST SERVICE
BIG SUR, CALIFORNIA

| Date | Duration | Time Period | Average Rainfall |
|---|---|---|---|
| 13 November | | | |
| Total rainfall period[1] | 12.25 hrs. | 0830 - 2045 hrs. | 0.40 inches/hr. |
| High intensity rainfall period[2] | 8.5 hrs. | 1215 - 2045 hrs. | 0.33 inches/hr. |
| 15 November | | 1400 - 1800; | |
| Total rainfall period[1] | 5.0 hrs. | 1900 - 2000 hrs. | 0.36 inches/hr. |
| High intensity rainfall period[2,3] | 1.0 hr. | 1700 - 1800 hrs. | 0.90 inches/hr. |

[1]Based on record of standard cumulative rainfall guage.

[2]Based on record of recording cumulative rainfall gauge, figure 3.

[3]During the period 1700 - 1715 hours, 0.44 inches of rain fell, or nearly half of that for the full one hour period.

The recent history at Big Sur may be only the beginning of a period of flood and mudflow activity that could continue for the next several years. The danger will be greatest during the early part of this period while the vegetation is recovering and the ground is healing. Much of the loose debris available to form mudflows, originally estimated at 29,600 cubic yards per square mile,[10] still lies waiting above Big Sur.

## ACKNOWLEDGMENTS

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# CALIFORNIA GEOLOGY

June 1973



Photos by W.J.Barry, California Department of Parks and Recreation.

↑ Foot-trail showing burned chaparral and erosion along the trail just north of Pfeiffer-Big Sur Park in the Pfeiffer-Redwood Creek watershed, Monterey County, California. The vegetation which normally insulated the steep slopes from effects of winter rainfall was almost completely destroyed when a wildfire developed in August 1972 on Highway 1 north of Big Sur Village and swept northeastward to the main ridge above Big Sur and southward along the east side of Big Sur Canyon.

↓ Looking down toward Pfeiffer-Big Sur Falls. The picture shows both rill and sheet erosion and burned chaparral resulting from the wildfire in August 1972.

↑ Buildings destroyed in the town of Big Sur, California, after a debris flow was crowded out of the Pheneger Creek channel in November 1972 and flowed north and west cutting across the Big Sur business area to the Big Sur River. Mudflows and debris flows reached inhabited sections of Big Sur several times during October and November storms. Evidence suggests that changes in vegetation and soil and rock properties resulting from a wildfire in August 1972 set the stage for later mudflows and debris flow events.

# FIRE + RAIN = MUDFLOWS

## BIG SUR

## 1972

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by George B. Cleveland, geologist
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Rainwater rushes down barren hillslopes, converges in narrow canyons, and bursts out onto broad valley floors that contain the main conduits along which streams flow to lower elevation. The water slices through brush and timber, increasing in density as it picks up loose soil, and plant and rock fragments along the drainage courses. At times it may slow, piling up against natural dams of debris or riding up onto projecting hillslopes. But when unopposed, it gathers speed and sound — the debris fragments clack and rumble as they are beaten together in the churning flow. The muddy train may slam into a community, pluck cars from the roads, ooze around houses and punch through windows, spilling destruction within. Eventually it slows and stops, its energy mostly dissipated in the ruin created along its path. This is a mudflow.

Although mudflows occur over wide areas of California each year, most of them slip by unnoticed. Only when they block a road or sail through a living room is much attention given to anything as mundane as mud. Yet mudflows are potentially more dangerous than other types of landslides because they can form with dramatic suddenness and move, at times, with astonishing velocity. Some have been clocked at over 50 miles per hour.[4] Because of their greater density, mudflows have a relatively higher destructive capability than do floodwaters, and, unlike flood waters, the mud doesn't recede after a storm has passed but may become a relatively permanent feature of the landscape.

A mudflow is more than just mud that flows. Fine grained particles usually make up the largest percentage of the solid material, but the balance can be all manner of rock fragments and plant debris. It is the fine grained component of the mix, however, that gives the flow its mobility. Each grain or aggregate of grains is encased in a film of water which insulates it from any hard knocks by its neighbors. This leads to reduced friction and increased mobility. Mixtures with the highest ratio of solid to liquid may move so slowly as to be classified as creep or slope wash deposits. As the amount of water increases the material may begin to slide as a discrete unit along a defined slip plane; this type of slope failure is called a mudslide or an earthslide. The mudflow phase is reached when the water content is sufficient for the mass to actually flow. Depending upon the nature of the solid material, the amount of water can range from 10 to 60 percent. As the ratio of solids to water changes, the density and viscosity change, and depending upon the gradient of the slope, the velocity and carrying capacity change as well. Relatively dense mudflows, some of which reach a density nearly two and a half times that of water, can support and transport exceptionally large rocks. One mudflow 4 feet thick transported a rock 9 by 11 by 16 feet; thicker flows have moved blocks 20 by 30 by 40 feet.[4] If the rock debris in the flow is mainly coarse fragments, such as cobbles and boulders, it may be called a debrisflow. Depending upon the volume and properties of a mudflow, the gradient of the slope, and the topography, mudflows can travel a few feet to tens of miles. In 1941 a mudflow at Wrightwood, in the San Gabriel Mountains near Los Angeles traveled about 15 miles.[16] Mudflows, the product of the amount of solid material and water available at any one site, may range widely in volume from a few cubic yards to millions of cubic yards. The mudflows at Wrightwood originate from a debris source estimated at 18 million cubic yards and individual flows have exceeded a million cubic yards.[14]

Mudflows may be associated with volcanic eruptions when great volumes of water from melting snow fields and glaciers or steam derived from the volcanic vent are introduced rapidly into poorly consolidated deposits of volcanic ash or other volcanic debris. But most frequently mudflows occur during intense rainfall. In climatic zones where the rainfall is frequently intense, there are two places where mudflows commonly originate: at the bases of steep slopes, and at the mouths of major canyons. During periods of normal stream flow it is at these locations, where stream gradients become gentle, that weathered rock and soil tend to accumulate. After they become saturated, these thick blankets of debris become the main source materials for mudflows when sufficient stream energy becomes available to move them.

# MUDFLOWS AT BIG SUR

Take one burned over forest slope, add intense rainfall, and stand back — instant mudflow. This recipe is well known and the events are predictable, yet precise causes of the mudflow phenomenon are not well understood. One example of mudflow evolution occurred recently at Big Sur, Monterey County, California, when nearby hills and canyons shed their skin of loose debris during a series of early season rainstorms. The geographic setting and the nature and sequence of events at Big Sur illustrate some of the conditions that can lead to the development of mudflows.

## The Setting

The sea, the mountains, and the forest dominate the Big Sur coast. Even its thousands of visitors, and those who live scattered along the lower reaches of the Big Sur River or adhering to the steep hillslopes facing the sea, are lost in significance in comparison with the greater dimension of the natural setting.

The Sur fault intercepts the Big Sur River as it flows westward out of the higher reaches of the Santa Lucia Range (see map). The river then trends northwest and follows the fault zone, cutting a sinuous defile in the more easily eroded rocks of the fault zone before it empties into the sea near Point Sur. Along this 5 mile stretch of the river is the Big Sur area. In contrast to the more gentle slopes and lower elevations on the southwest of the fault zone, to the northeast, Big Sur is crowded against a mountain front which rises abruptly to more than 3500 feet. Slope angles range from about 15 degrees to 90 degrees with most slopes between 25 and 40 degrees.[10] Off this rock wall flow several minor tributaries to the Big Sur River, and on three of these tributaries damaging mudflows originated in 1972.

The Sur fault zone separates the dissimilar rocks of the ancient Sur Series on the northeast, from the younger Franciscian Formation on the southwest.[12] The Sur Series in this area is comprised of hard metamorphic rocks, largely gneiss, quartzite, and limestone; the rocks of the Franciscian Formation are mainly sandstone and shale. A narrow belt of fine- to coarse-grained sandstones, and

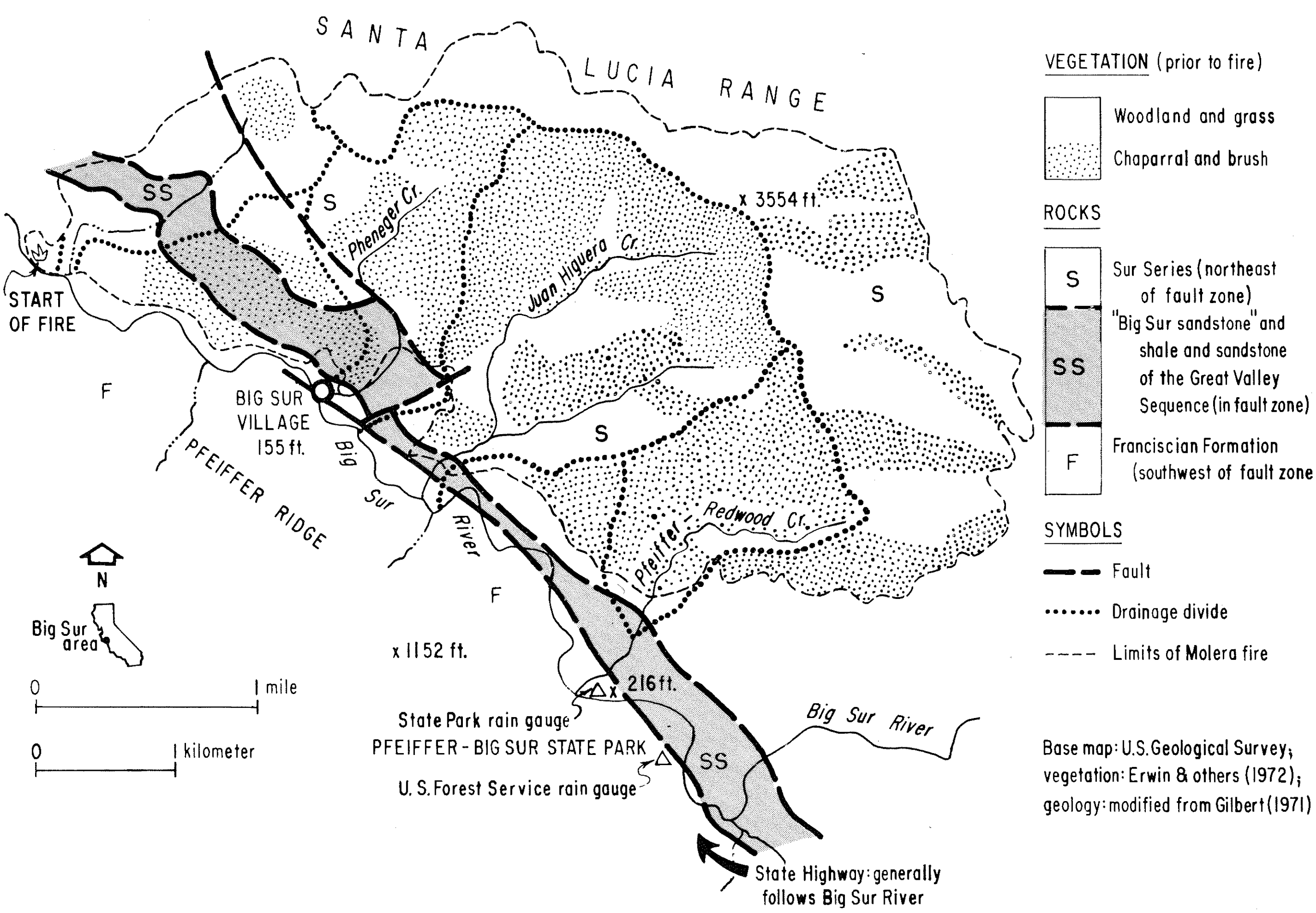
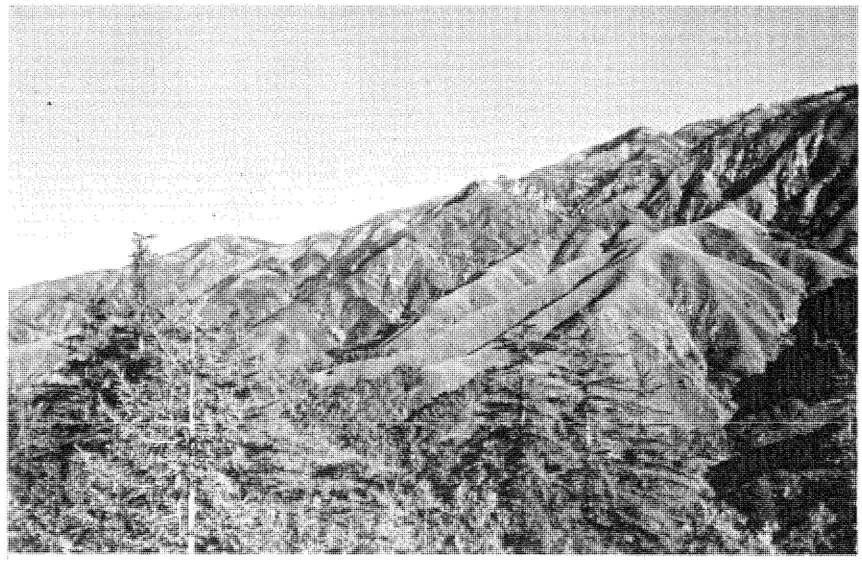



Figure 1. Geologic and geographic sketch map of Big Sur area, California.

Figure 2. Molera fire which occurred in early August 1972 left baked slopes above Big Sur. View north.



conglomerate and shale is sandwiched between the other two rock units and forms the core of the fault zone. The rocks in the fault zone are part of the Great Valley Sequence and the "Big Sur Sandstone" (see map).[12] They form a weak foundation along the base of the hillslopes northeast of the Big Sur River and are more easily weathered and eroded than those of the Sur Series that are stacked above them. The weathered debris from the Great Valley Sequence and the "Big Sur Sandstone" is mainly sand and clay; debris from the Sur Series is coarse angular blocks of gneiss. These and other rock materials have been classified into several soil types.[10] The soil types are all generally similar — coarse grained, shallow, and moderately erodable. Erosion rates vary widely, however, and depend upon local conditions within each drainage basin. The thin soil cover and the impermeable bedrock below leads to rapid runoff.

Big Sur, lying near sea level, receives about 40 inches of rainfall annually giving it a somewhat humid climate and a vegetation cover to match.[6] Higher elevations nearby drain toward Big Sur and receive an annual rainfall of from 50 to 60 inches.[10] But these annual rainfall figures reveal little with respect to the extremes of weather, especially in terms of rates of rainfall and runoff.

Both short and long duration rainfall totals are related to the landslide process, but short duration high intensity rainfall appears to be most closely related to mudflow activity. Less intense rainfall of longer duration mainly influences massive soil and bedrock landslides.

The rainfall intensity figures for the Big Sur area, when compared with those from other parts of California, show that short term rainfall is relatively high in the Big Sur region. Rainfall commonly will reach intensities equivalent to 0.8 inches per hour. Much higher rates per hour are reached for shorter durations.[17] Only local areas in the Transverse Ranges in the southern part of the state, and the Santa Cruz Mountains to the north, can normally expect slightly higher *intensity* rainfall than that of coastal Monterey and San Luis Obispo Counties.

In contrast to both intensity and total annual rainfall, single-storm rainfall totals around Big Sur are generally lower than single-storm totals for most of the rest of the California coast. But compared to many interior parts of the state and for the western states generally, storm totals in the Big Sur region are significantly higher.[13]

The Big Sur River drains a relatively small region of about 46 square miles, but storm rainfall totals within the region vary widely. It is common for the lower reaches of the river to flood. Weather records indicate that the Big Sur River drainage basin has a mean annual rainfall of about 51 inches, of which roughly half runs off. This amounts to a mean runoff of about 63,000 acre-feet. During 7 non-consecutive years of severe storms and resultant flooding between 1931 and 1960, runoff was very high, reaching a high of 177,500 acre-feet in 1941. The lowest runoff was in 1931 when only 8100 acre-feet were recorded.[1] Thus, it may be inferred that the capacity of the stream courses will not accommodate the runoff without flooding during peak years of high rainfall.

The influence of rainfall on the formation of mudflows is dependent upon other conditions as well. The character and density of the vegetation has a profound influence on regulating the way in which the rainfall is dissipated. The plants prevent the falling raindrops from hitting the soil at a high velocity, allowing a greater amount of the moisture to enter the soil rather than to run off over the surface and erode away the soil. Once the moisture is absorbed by the soil, part of it is taken up by the plant which returns most of it to the atmosphere by transpiration. Plants also impart strength to the soil through their interlocking roots which help to prevent the soil from moving down slope. Other conditions being the same, this root mat tends to allow steeper slopes to be maintained than where the vegetation is either more sparse or absent. The influence of the vegetation is further dependent upon the kinds of plants represented. Different plant types, because of their physiology, will utilize and dissipate the ground moisture in various ways. The nature of their root structure also will bear on the gross strength of the soil.

In the Big Sur area the slopes are mantled mainly with chaparral and grass, but stands of timber grow locally in the canyon bottoms. Chaparral is a collective term for a group of similar shrubs and small trees which make up the dull, grayish green, velvet-like cover on much of the coastal ranges of California. The composition of the chaparral community is not everywhere the same, but changes in concert with local soil and climatic conditions. At Big Sur it is composed of coast live oak, laurel, tan oak, chamise, ceanothus, toyon, and manzanita among other plants. Trees in the canyon bottoms are the coast redwood, sycamore, madrone, cottonwood, maple, alder, and willow. Chaparral comprises about 65 percent of the plant cover with trees and grass comprising the remainder in about equal amounts.[10]

## The Events

If the vegetation did not normally insulate the steep slopes from the effects of winter rainfall, the mountains above Big Sur would regularly shed torrential amounts of runoff. Even the vegetative cover is not always sufficient to completely offset periodic high intensity rainfall.

### Molera Fire

On 1 August 1972, the tenuous equilibrium between the rainfall and the vegetation, soil, and slope that existed on the mountainsides was almost completely destroyed when a wildfire developed west of Highway 1, north of Big Sur Village. It swept northeastward to the crest of the main ridge above Big Sur and southward along the east side of Big Sur Canyon. It was contained at a cost of about $850,000 on 6 August after burning 4300 acres of chaparral, grass, and timber (figures 1 and 2).[10] The natural beauty of the canyon floor with its vegetation escaped destruction, but it lay below a baked and largely disrobed landscape to the east. The fire burned through four basins tributary to and northeast of the lower Big Sur River — Pfeiffer-Redwood Creek, which flows through the State Park, Juan Higuera Creek, Pheneger Creek, and an unnamed creek a mile northwest of Big Sur Village.

The intensity of the heat from the fire, especially where it was fueled by dense thickets of low growing chaparral, baked the surface of the soil to a bright red and brown crust. Trees burned vigorously in some side canyons, but elsewhere they were left only slightly charred with their leaves prematurely turned to autumn colors.

### Rain

Next came the rain. In a series of storms beginning in mid-October and lasting for several days, and then again in mid-November (tables 1 and 2); both storm periods brought flooding and mudflow activity. The second period was the more destructive.

The first storm yielded 5.07 inches of rain from 10 October through 17 October. The major drainages were flooded during this period, but mudflows occurred only on 12 and 15 October, during intense, short duration rainfall. The mudflow on 12 October followed 0.82 inches of rain, most of which fell within an hour; that on 15 October followed rainfall of 0.73 inches, which was recorded between 0800 and 0900 of that day.

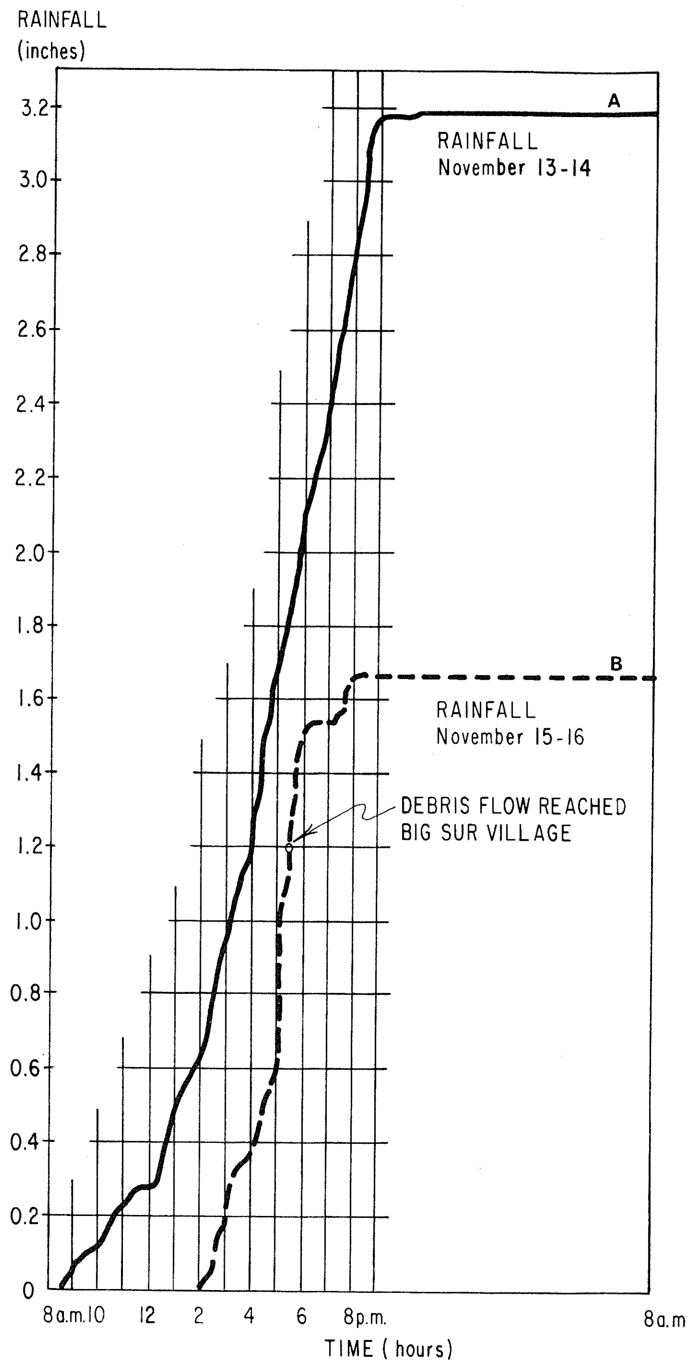



Figure 3. Graph showing the cumulative rainfall for 13-14; 15-16 November at Big Sur, California, as measured by a recording rain gauge. The total rain fall shown does not represent the total amount of rain for the 24 hour period. See Table 2 for correct totals. Differences are caused by the inaccuracies introduced by the recording rain gauge apparatus. The accuracy of this apparatus decreases with increased rainfall. *Courtesy of U.S. Forest Service weather station, Big Sur.*

## TABLE 1: RAINFALL, OCTOBER STORM, BIG SUR, CALIFORNIA - 1972

Weather station at Pfeiffer-Big Sur State Park; rainfall recorded daily at 0800 for previous 24 hour period.

| Date | Rainfall | Remarks |
|---|---|---|
| Prior to 10 October | 0.18 inches | |
| 10 October | 0.32 | |
| 11 | 0.01 | |
| 12 | 0.82 | Most fell during a short period around 0700. |
| 13 | 0.05 | |
| 14 | 0.93 | |
| 15 | 1.02 | 0.73 inches fell between 0800 and 0900. |
| 16 | 0.82 | |
| 17 | 1.10 | |
| Storm total | 5.07 inches | |

Data from: California Department of Parks and Recreation, Pfeiffer-Big Sur State Park

The rainfall during the November storm was measured on a continuous recording rain gauge installed after the October storm by the U.S. Forest Service. This record gives more precise data in terms of critical rates of rainfall and the beginning of the mudflows, although it less accurately records total amount of rainfall. Figure 3, curve A shows the rate of rainfall for the 24 hour period between 0800 hours 13 November and 0800 14 November. Although total rainfall was high (4.98 inches as measured by standard, non-recording, cumulative rainfall gauge), the short term hourly rate was not as great as for the period 15-16 November when a 24-hour total of 1.79 inches fell (figure 3, curve B). The 13-14 November curve shows a steady heavy rainfall beginning at 0830 and ending about 2100; no mudflows reached Big Sur during this period. The curve for 15-16 November indicates heavy rainfall began in the early afternoon and reached its highest intensity beginning at 1700 when 0.44 inches fell in 15 minutes. After this surge, it took another 15 minutes for the runoff to accumulate and mix with debris and race down Pheneger Creek, for at 1730 on 15 November a debris flow, estimated at several thousand cubic yards, struck Big Sur Village.

The rain gauges were not in the drainage basins from which the mudflows originated, but were along the Big Sur River. Furthermore, because of the high mountains to the northeast, rainfall intensities at higher elevations may have been significantly greater. Stream flow measurements would be more meaningful if they were available.

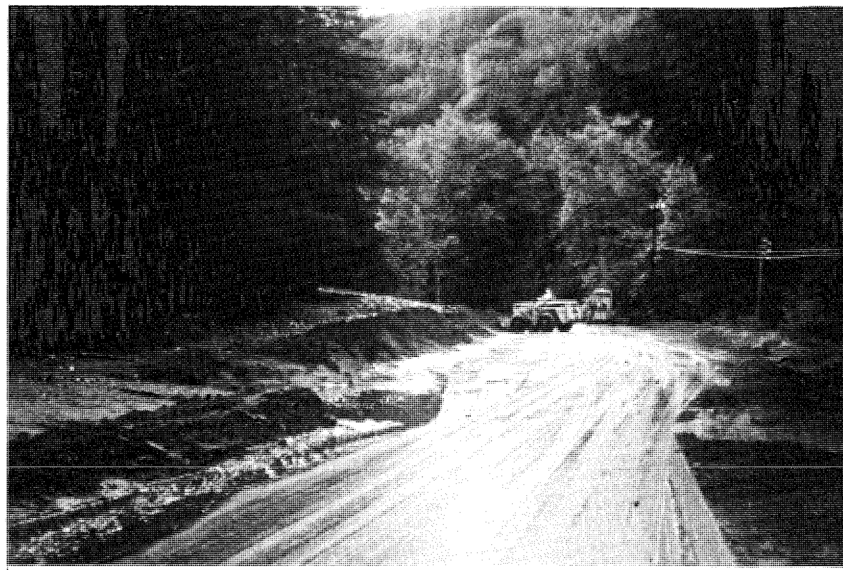
## TABLE 2: RAINFALL, NOVEMBER STORM, BIG SUR, CALIFORNIA - 1972

Weather station at Pfeiffer-Big Sur State Park and U.S. Forest Service, Big Sur; rainfall recorded daily at 0800 for previous 24 hour period at both locations.

| Date | Rainfall | | | Remarks |
|---|---|---|---|---|
| | State Park | Forest Service | Recording Gauge | |
| 10 November | 0.88 inches | 0.80 inches | | |
| 11 | 1.27 | 1.15 | | |
| 12 | 0.28 | 0.27 | | |
| 13 | tr | 0.0 | | |
| 14 | 4.70 | 4.98 | 3.18 | Flooding only on 13-14 November |
| 15 | 2.47 | 2.38 | 1.65 | Destructive debris flow occurred at 1730 15 Nov. after 0.44 inches of rain fell in 15 minutes |
| 16 | 1.83 | 1.79 | | |
| 17 | 0.15 | — | | |
| 18 | 0.01 | — | | |
| Storm total | 11.59 inches | | | |

Data From: California Department of Parks and Recreation, Pfeiffer-Big Sur State Park; and U.S. Forest Service, Big Sur

Figure 4. Mudflows repeatedly closed Highway 1 at Pfeiffer-Big Sur State Park during storms of October and November 1972. Mudflows jumped the bed of Pfeiffer-Redwood Creek and crossed the highway to the Big Sur River (out of sight to the right). View southeast.



## Mudflows

During the storm periods of late 1972 three of the four creeks draining into the Big Sur River at Big Sur would at one time yield relatively clear water and at another time a mudflow or debris flow. Generally, Pfeiffer-Redwood Creek carried fine grained materials and only mudflows occurred along this drainage course (figure 4). The size of the debris fragments was greater on the creeks to the north and at Pheneger Creek, blocks of rock 8 feet in greatest dimension and trees 4 feet in diameter were carried along, within, or riding atop the flows (figure 5). Juan Higuera Creek carried relatively smaller volume mudflows than did the other two creeks.

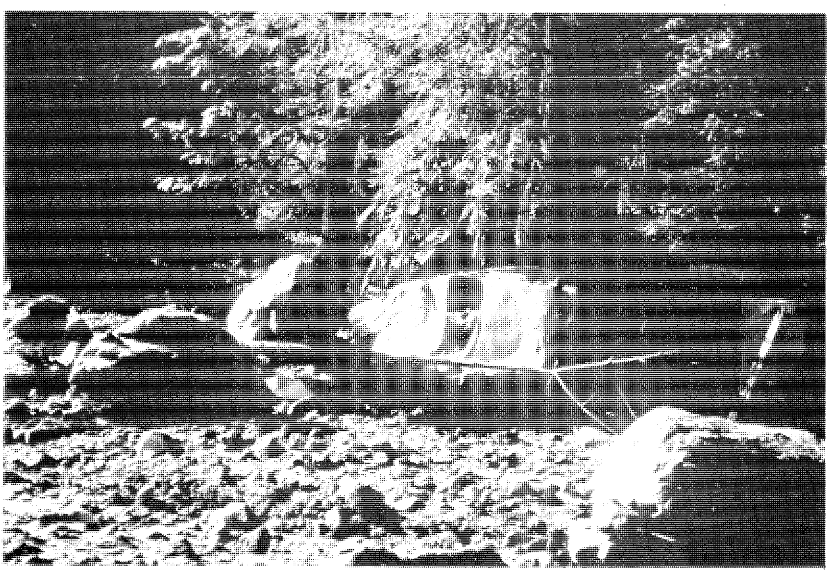


Figure 5. Large boulders, some 8 feet in greatest dimension, rode atop the debris flow that struck Big Sur Village on 15 November, 1972. Debris shown here came to rest in the Post Office parking lot. An automobile was crushed between a large boulder and a tree. Fifteen other vehicles met a similar fate and four were known to have been washed into the Big Sur River.

The notable difference in grain size between the flows that originated on Pfeiffer-Redwood Creek and those farther north is difficult to explain; compare figures 4 and 5. The available source materials for all the flows is debris that accumulates near the mouths of the tributaries to the Big Sur River and the blanket of soil that mantles the hillslopes. These materials are derived from the face of the massif behind Big Sur which is mainly crystalline rocks and younger sedimentary rocks. The sedimentary rocks are of the Great Valley Sequence north of the cross fault near Pheneger Creek, and "Big Sur Sandstone", to the south. Although both units are mainly sandstones, some shale occurs with sand in the section to the south. This difference in lithology, the erosion of soil left unprotected after the fire, or the possibility that Pfeiffer-Redwood Creek failed to develop enough energy to move larger clasts, may account for the finer grained flows along this creek.

The volume of some of the flows was estimated to be on the order of 10,000 cubic yards. The estimates were difficult to make because succeeding flows overrode previously deposited flows, masking their original dimensions. Moreover, the ratio of solids to liquid ranged widely and after a flow stablized it "deflated" as the water drained away.

Some of the flows apparently moved at high velocity and generally in one or a few distinct pulses. Although no estimates are available, eyewitnesses could hear the flows approaching and were forced to run from their paths. Probably these flows traveled a few tens of miles per hour. The mudflow at the State Park on 12 October, however, moved relatively more slowly judging from the observations of State Park personnel. They noted that this flow moved about half a mile in 10 minutes, or about 3 miles per hour.

The mudflows and debris flows reached the inhabited sections of Big Sur several times during the October and November storms. The state highway was blocked by flows

Figure 6. Debris flow of 15 November 1972 inundated the Big Sur Village, damaged buildings, and swept vehicles ahead of it toward the Big Sur River, beyond the trees.

and numerous homes and business buildings were inundated by mud and water. The most devastating events occurred when the flows were diverted by previously deposited debris or when they jumped the drainage channels and moved into habited areas along unexpected routes.

On 15 November a debris flow was crowded out of the channel of Pheneger Creek at Big Sur Village and flowed toward the north and west cutting across the business area to the Big Sur River. It blocked the highway with a train of debris 6 feet thick, plowed through a cement block building, climbed up and around the lower story of the two story building that houses the post office, and farther beyond dropped a tow truck onto a house trailer. In all it smashed a dozen cars or more into trees and rocks and into each other, then rafted four of them to the river where one of them was washed downstream 2 miles from the village (figures 6 and 7).

Of the numerous ways in which mudflows originate, those associated with the "fire-flood sequence" have been studied in most detail. Although much remains to be learned, one of the most notable aspects of the events at Big Sur, is that they were predicted with uncanny accuracy well before they took place. A team of hydrologists, foresters, and pedologists, from the U.S. Forest Service, the U.S. Soil Conservation Service, and the California Division of Forestry, began an investigation of the area after the August 1972 fire and prepared a Forest Service report that gives a detailed chronology of what was to come.[10] Their conclusions were reached by measuring how the bedrock, soil, vegetation, and slope would react to expected weather conditions based on the climatic pattern of the region. From these data estimates were made of the amounts of debris available for transport by the stream, erosion and runoff rates, and what remedial measures could be taken to reduce the danger from flooding and mudflows.


Figure 7. Ironically, this establishment at Big Sur Village lived up to its name when some of the flow from Pheneger Creek chose to cut through a parking lot on its way to the Big Sur River.

## The Reasons

The cause of the mudflows at Big Sur may be traced to properties of the rocks and soils, and to the pattern of the rainfall during short time periods. The evidence suggests that the changes brought on by the fire set the stage for later mudflow and debris flow events.

During the October storm when mudflows were occurring at Big Sur, no other drainage courses from Big Sur south to the San Luis Obispo County line showed either mudflow activity or excessive runoff at the shoreline, even though rainfall appeared to be general all along the coast.

Three drainage basins within the fire area yielded mud—or debris flows—the fourth only flooded. Mudflow activity or flooding was not observed in drainage basins in which the vegetation was unaffected by the fire, even though the unburned basins lay adjacent to the fire zone. Moreover, as far back as 1910, local residents cannot recall any large mudflows, although the Big Sur area has been flooded several times during that period.

The already steep and largely impervious slopes were probably modified by the fire through changes in the physical and chemical regimen of the soil at, and just below, the ground surface. This could have occurred when the protective canopy of vegetation was destroyed and certain organic compounds were redistributed in the soil.

The loss of the plant cover exposes the ground to direct impact of the raindrops which reduces the infiltration capacity and increases runoff.[9] Without the plants to intercept the rainfall, the soil absorbs a smaller amount of moisture. The rainfall does not collect and run off along established depressions on the slope, but is dissipated rapidly as sheet flow.

Some evidence suggests that another mechanism may have conditioned the ground surface and increased the run off at Big Sur. After a heavy rainfall during the October storm period, members of the U.S. Forest Service examined the slopes above Big Sur in the fire area. The ground surface was moist, but by kicking into the soil a dry zone a few inches below the surface was uncovered. This indicated that, at least locally, a recently recognized phenomenon known as non-wettable or hydrophobic soil may have developed.[8] Hydrophobic soils are a particular product of fires in chaparral terrain.

Under a chaparral cover ammonium hydroxide and other organically derived compounds accumulate in the soil. These compounds contribute to the hydrophobic character of the soil. They are more concentrated below plants such as chamise (*Adenostoma fasciculatum*), but they also occur below other plants of the chaparral community: mountain mahogany, scrub oak and certain species of *Ceanothus*, among others.[8] When these plants burn, intense heat is generated. Above the ground surface, the temperature can reach 2000 degrees Fahrenheit. At the ground surface it can reach 1200 degrees, but because of the low heat conductivity of soil, the temperature drops off to 350 to 550 degrees F about 2 inches below the soil surface.

Laboratory experiments indicate that at high temperatures hydrophobic compounds are vaporized and part of the vapor condenses in a zone of concentration a few inches below the ground surface, forming an impervious layer. In these experiments, slightly non-wettable soils were heated above 400 degrees F for 5 to 20 minutes whereupon their hydrophobic properties increased, but when the temperature reached 800 to 900 degrees F, the hydrophobicity was destroyed.[7]

The implications of these relationships with regard to the origin of mudflows are far reaching. If a slope is burned over by a fire of intense heat, the near surface zone is purged of hydrophobic compounds. The vaporized compounds condense in a cooler zone just below the surface. Rainfall could then penetrate the surface layer and reduce its shear strength. Any excess water would migrate downslope, just above the impervious layer, carrying away the weakened material as a mudflow. All or part of this mechanism may have been important in forming the mudflows at Big Sur.

With the physical properties of the ground favoring rapid run off, the prolonged, and at times, high intensity rainfall of October and November reached critical levels with respect to debris transport. On some days, steady rainfall of relatively high total volume, apparently drained over or through the debris stored in the stream courses without much of the debris being transported (tables 1 and 2). The principal mudflow and debris flow activity occurred during or just after short periods of intense precipitation following a previous longer period of relatively steady, but not intense rainfall. The periods of intense rainfall yielded a volume of water flow that could not filter through the debris fast enough to be dissipated simply as flood water.

Because of the range of conditions that control runoff and subsequent debris transport in each of the drainage basins, no quantitative measure of rainfall intensity can be cited as being critical with respect to the formation of mudflows. Mudflows followed periods of rainfall with intensities of about 0.82 inches per hour, 0.73 inches per hour, and the destructive mudflow after 0.70 inches per hour.

Table 3 shows average hourly rates of rainfall of similar nature for the time periods on the curves in figure 3. Average hourly rates for the two total rainfall periods are comparable, but the high intensity of the rainfall on 15 November was nearly three times the intensity of the rainfall on 13 November, even though it was of much shorter duration. The highest intensity rainfall on 15 November, just prior to the major mudslide, lasted for only 15 minutes. No quarter hour intensity rates on 13 November even came close to the intensity recorded on 15 November. These data suggest that mudflow activity may depend less on total daily rainfall and more on relatively higher hourly rates followed by shorter bursts of precipitation. But antecedent rainfall of several hours or days undoubtedly primes the terrane in terms of lowering its infiltration capacity by saturating the ground. Thus, less of any subsequent short duration, higher intensity rainfall infiltrates into the ground, leading to greater rates of runoff and subsequent mudflow activity.

## TABLE 3: AVERAGE HOURLY RAINFALL INTENSITY NOVEMBER STORM, 1972, U.S. FOREST SERVICE BIG SUR, CALIFORNIA

| Date | Duration | Time Period | Average Rainfall |
|---|---|---|---|
| 13 November | | | |
| Total rainfall period[1] | 12.25 hrs. | 0830 - 2045 hrs. | 0.40 inches/hr. |
| High intensity rainfall period[2] | 8.5 hrs. | 1215 - 2045 hrs. | 0.33 inches/hr. |
| 15 November | | | |
| Total rainfall period[1] | 5.0 hrs. | 1400 - 1800; 1900 - 2000 hrs. | 0.36 inches/hr. |
| High intensity rainfall period[2,3] | 1.0 hr. | 1700 - 1800 hrs. | 0.90 inches/hr. |

[1]Based on record of standard cumulative rainfall guage.

[2]Based on record of recording cumulative rainfall gauge, figure 3

[3]During the period 1700 - 1715 hours, 0.44 inches of rain fell, or nearly half of that for the full one hour period.

The recent history at Big Sur may be only the beginning of a period of flood and mudflow activity that could continue for the next several years. The danger will be greatest during the early part of this period while the vegetation is recovering and the ground is healing. Much of the loose debris available to form mudflows, originally estimated at 29,600 cubic yards per square mile,[10] still lies waiting above Big Sur.

## ACKNOWLEDGMENTS

Thomas H. Rogers and John W. Williams, geologists, California Division of Mines and Geology assisted with the field examination of the Big Sur area; Robert L. Allen, Chief Ranger, Pfeiffer-Big Sur State Park and Richard D. Harrell, District Ranger, U.S. Forest Service, kindly offered their observations and made available unpublished information related to the events at Big Sur.

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CHAPTER 14

# Central Coast Bioregion

FRANK W. DAVIS AND MARK I. BORCHERT

Branches broken by this storm in one night added more fuel than had accumulated in more than thirty years of fire control. Thus, the stage was set for the fury that erupted when lightning set four fires in the Ventana Wilderness.

JIM GRIFFIN *on the Marble Cone fire of 1977*

## Description of Bioregion

The Central Coast bioregion includes the Central California Coast and Central California Coast Ranges Sections (Map 14.1) (Miles and Goudey 1997) in the California Coastal Chaparral Forest and Shrub Province of the Mediterranean Division of the Humid Temperate Domain (Bailey 1995). The bioregion extends from Napa County south to northern Santa Barbara County, altogether covering 38,830 $km^2$ (14,992 $mi^2$). The eastern boundary of the bioregion adjoins the western edge of the San Joaquin Valley. Familiar coastal landmarks include San Francisco Bay, Monterey Bay, Big Sur, and Morro Bay. Notable interior landmarks include Mt. Diablo, San Benito Mountain, and the Carrizo Plain.

### Physical Geography

The topography of the region consists of rugged, northwest-to-southeast trending ranges, notably the Santa Cruz Mountains, Santa Lucia Ranges, San Rafael Mountains, Diablo Range, Gabilan Range, and Temblor Range. Expansive intervening valleys include the Santa Clara, Salinas, and Santa Maria River valleys. Elevations range from sea level to over 1,800 m (5,906 ft). Half of the area in the Central California Coast Section is below 160 m elevation (525 ft), versus 488 m (1,600 ft) in the Central California Coast Ranges.

Geology exerts a strong control on landforms, soils, and vegetation of the region (Wells 1962, Griffin 1975). The lithology of the region is dominated by folded and faulted Cenozoic marine and nonmarine sediments, with the exception of the northern Santa Lucia Range and northern Gabilan Range, which are composed of Mesozoic granitic and Triassic metamorphic rocks. Marine sediments are predominantly interbedded sandstones and shales.

In the Central California Coast Section, rugged terrain, complex geology, local topo-climatic variability and disturbance history result in complex local vegetation mosaics (Wells 1962). In general, upland natural vegetation changes from coastal prairies and coastal sage scrub below 300 m (984 ft) through chaparral-dominated slopes to roughly 1,200 m (3,937 ft), to montane hardwood and mixed hardwood forests at the higher elevations. Conifer forests are prevalent at elevations above 1,500 m (4,921 ft). Interior valleys and annual grasslands, oak woodlands, and chaparral-dominated foothills lie to the east of the coastal ridges. Annual grasslands, semi-desert chaparral, and oak woodlands dominate the driest interior portion of this section.

Azonal grasslands, shrublands, and woodlands are associated with scattered serpentinite outcrops of the Mesozoic Franciscan Complex, a mélange of metamorphosed sedimentary and volcanic rocks. These outcrops are especially widespread in the South Coastal Santa Lucia Range. In the Diablo Range, San Benito Mountain is the upper portion of a highly altered ultrabasic plug with large patches of highly mineralized serpentine (Griffin 1975). Stabilized Pleistocene sand dunes support distinctive maritime chaparral vegetation in the Santa Maria and Salinas River valleys, east of Pismo and Morro Bays and at other stretches near the coast as far north as Sonoma County (Van Dyke and Holl 2001).

### Climatic Patterns

The regional climate is strongly mediterranean with cool wet winters and warm dry summers. More than 80% of seasonal rain falls between November and March, primarily due to occluded fronts and occasional cold fronts from the west-northwest (Null 1995). Precipitation decreases from north to south, but topography exerts an equally strong influence on climate with the highest rainfall in the coastal mountains and lowest rainfall in rain shadows along the eastern edge of the region (Map 14.2). To illustrate these patterns, at the northern end of the region, long-term mean annual precipitation decreases from 1,250 mm (49.2 in) in Big Basin Redwoods State Park to 767 mm (30.2 in) in Santa Cruz to 427 mm (16.8 in) at Pinnacles National Monument. At the southern end of the region, mean annual rainfall ranges from 575 mm (22.7 in) at San Luis Obispo to 140 mm (5.5 in) at interior station Cuyama. In general, the highest rainfall is associated with El Niño years and lower rainfall with La Niña years (Cayan et al. 1999).

Seasonal temperatures also vary considerably with latitude, elevation, and distance from the coast (Map 14.3) (Thornton et al. 1997). At coastal stations, mean monthly temperatures at sea level range from 10°C–13°C (50°F–55°F) in the winter months to 16°C–18°C (60.8°F–64.4ºF) in the summer, with highest temperatures in August through October. The coastal ranges prevent a strong marine influence from reaching more than a few kilometers inland from the coast except via large river valleys, and inland temperature regimes are considerably more continental. For example, mean daily maximum temperatures at coastal Morro Bay for the period 1959–2001 ranged from 16.7°C (62°F) in January to 20.8°C (69.4°F) in October. In contrast, 30 kilometers inland at Paso Robles mean daily maximum temperatures range from 15.2°C (59.4°F) in January to 34.5°C (94.1ºF) in July.

#### WEATHER SYSTEMS

During the fire season, Santa Ana conditions (see Keeley, this volume) are most likely to occur during the fall (Sommers 1978). At the southern end of the region, Santa Ana conditions and local foehn winds increase the risk of large wildfires (Davis and Michaelsen 1995, Moritz et al. 2004). Further north, the relative location of the high-pressure center over Utah and Nevada, as well as the northwest-southeast axis of the Central Coast Ranges, limits the development of strong Santa Ana conditions, but foehn winds can still be locally important.

Summer convective storms and accompanying lightning activity are uncommon in the Central Coast due to a strong atmospheric inversion and cool coastal marine layer. In fact, except for the Northern California Coast, the Central Coast has the lowest incidence of lightning strikes of any region in the state. Lightning network data since 1985 indicate an average of only 2.99 strikes per 100 $km^2$ per year in the Central Coast bioregion compared to 27.26 strikes/100 $km^2$/yr for the Sonoran Desert bioregion of California or 19.60 strikes/$km^2$/yr for the Sierra Nevada bioregion (Jan van Wagtendonk, personal communication; see also Keeley 1982, Keeley 2002a, Keeley and Fotheringham 2003). Lightning-ignited wildfires are accordingly rare but in the right weather and fuel moisture conditions they can become quite large, as exemplified by the 72,500 ha (179,150 ac) Marble Cone fire of 1977 in the northern Santa Lucia Mountains.

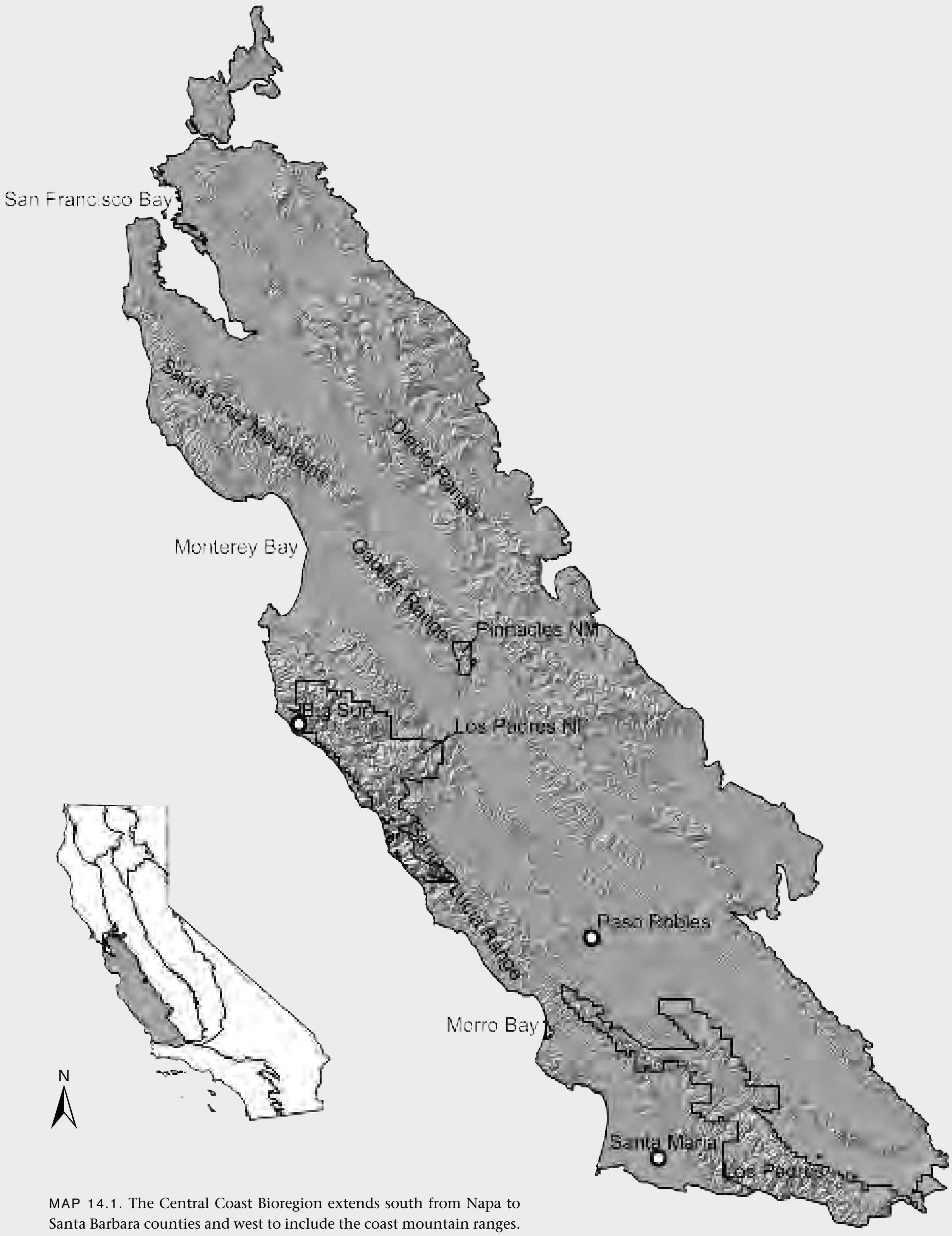
Live fuel moisture of chaparral in the region peaks in April and declines steadily to minimum levels in September and October (Fig. 14.1). This general pattern is observed at stations throughout the bioregion, but there is high local variation as well as marked inter-annual variability in fuel moisture associated with late winter and spring precipitation (Davis and Michaelsen 1995). Between 1976 and 1999, the lowest minimum summer fuel moisture levels (48%–55% across stations) occurred during the multi-year drought from 1984 to 1988. Highest minimum summer fuel moisture levels (60%–78%) followed strong El Niño years (1982–1983, 1997–1998).

Long-term rainfall history data from station records and tree rings indicate two to seven-year wet-dry cycles in coastal California between San Francisco and San Diego for at least the past 400–600 years (Michaelsen et al. 1987; Haston and Michaelsen 1994, 1997). There is no clear relationship between annual precipitation and the El Niño Southern Oscillation (ENSO) over the long-term record. The Central Coast often shows the opposite pattern to southern California south of Point Conception, so that wet years in the south often coincide with dry years in the north, and vice-versa (Haston and Michaelsen 1997).

There is evidence of 20- to 50-year fluctuations in Central Coast rainfall and even longer-term precipitation patterns including a generally wetter climate during the sixteenth and seventeenth centuries followed by a relatively drier climate during the eighteenth and nineteenth centuries (Haston and Michaelsen 1994). Furthermore, the magnitude of climate variability has fluctuated considerably over 50- to 150-year periods and there is evidence that variability has been increasing during the past 30 to 40 years (Haston et al. 1988, Haston and Michaelsen 1997). Such variation in rainfall could have affected the incidence and extent of wildfires in the Central Coast during different eras. Analyzing climate and fire data from 1913 to 2001, Keeley (2003) found a weak but significant positive relationship between the Palmer Drought Severity Index (PDSI) for the current year and fire occurrence in the Central Coast (correlation $r = 0.23$, $p < 0.05$) and a modest relationship between previous-year index and fire occurrence ($r = 0.45$, $p < 0.01$). However, there was only a weak positive relationship between the index and total area burned (Keeley 2003). The weak relationship between PDSI and fire in this region is in contrast to stronger relationships observed in other regions of the western U.S. (Westerling et al. 2003) and probably indicates the stronger control exerted by autumn foehn wind events than by fine fuels or fuel moisture levels on wildfire risk in the region (Keeley 2004, discussed below).

### Human Geography

Since the early Holocene, native peoples have occupied the Central Coast bioregion at relatively high population densities, especially along the immediate coastal plains, foothills, and valleys, where densities may have averaged one to three persons per $km^2$ (Beals and Hester 1974, cited in Keeley 2002). Spanish settlement began in earnest in the last quarter of the eighteenth century with the construction of missions and the low but steady influx of new settlers during the Mexican era from 1836 to 1850. The population climbed gradually through the early twentieth century and rapid growth did not commence until the 1940s, especially in Bay-area counties (Fig. 14.2).




MAP 14.1. The Central Coast Bioregion extends south from Napa to Santa Barbara counties and west to include the coast mountain ranges.

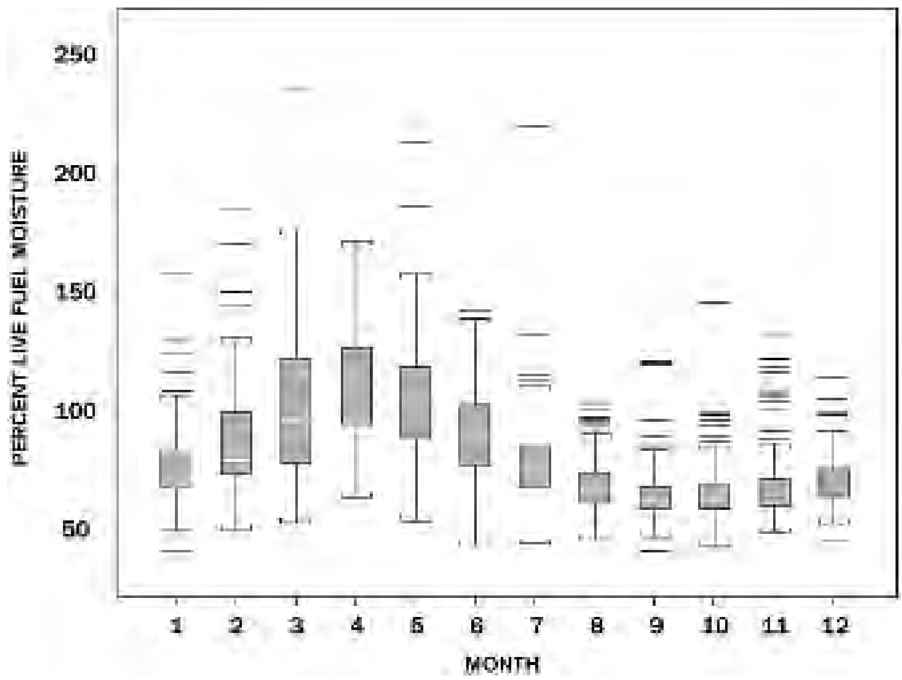



FIGURE 14.1. Boxplots of monthly percentage of live fuel moisture data for chamise sampled from seven locations, Monterey to Santa Barbara County, in Los Padres National Forest. (Data from 1976–1999, courtesy of Los Padres National Forest.)

Most of the population increase has occurred near the coast, whereas the interior of the region remains rural. Today the region is still sparsely settled with the exception of the Bay area and smaller urban centers such as Santa Cruz, Monterey, Salinas, Paso Robles, San Luis Obispo, and Santa Maria. Eighty-seven percent of the region has a housing density of less than one house per 8 ha (20 ac). With the exception of the large wilderness areas, a dense network of public and private roads accesses these rural lands. For example, excluding major state and interstate highways, a 50-m (164-ft) buffer on either side of the mapped roads (U.S. 2000 TIGER data) of Santa Cruz County encompasses roughly 25% of the county. In Monterey and San Luis Obispo Counties the same buffers enclose 15% and 13%, respectively. In general, road-buffer areas range from more than 80% in densely developed areas to less than 20% in rural, sparsely roaded areas of California.

Seventy-eight percent of the region is privately owned. Los Padres National Forest is the largest public landowner with 983,300 ha (2,429,720 ac) in the region, including large wilderness areas in the northern and southern Santa Lucia Ranges. Other large tracts of public land include Fort Hunter-Liggett, comprising 66,800 ha (165,066 ac), which adjoins Los Padres National Forest in southern Monterey County; Fort Ord (11,237 ha [27,767 ac]) on Monterey Bay; and Pinnacles National Monument (5,396 ha [13,333 ac]) in San Benito County.

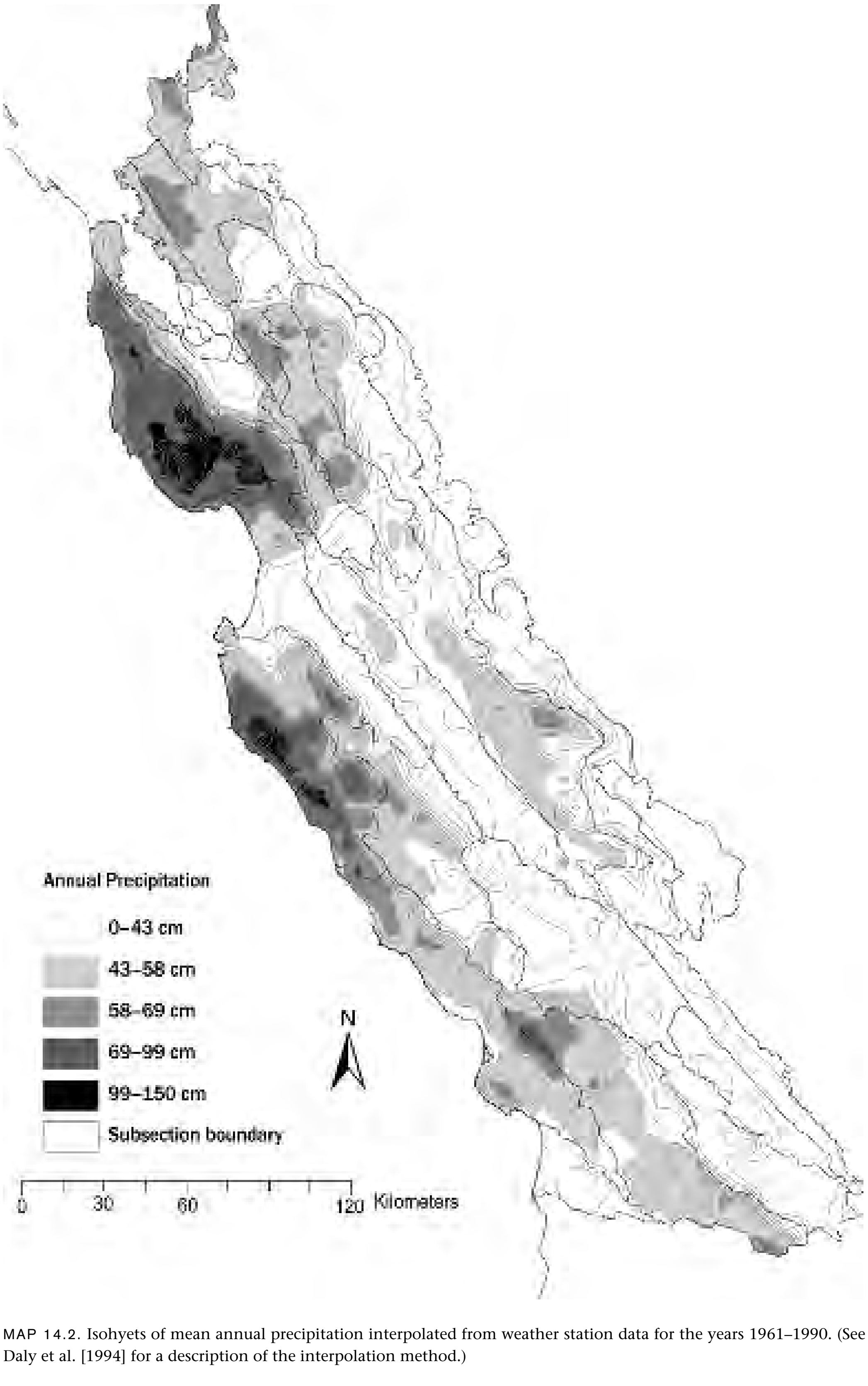
## Ecological Subregions

Miles and Goudey (1997) divided the California Coast Ranges and Central California Coast Ranges Sections into 23 ecological subsections based on geology, geomorphic processes, soil groups, subregional climates, and potential natural plant communities (Table 14.1, Map 14.4). To help discriminate systematic geographical variation in environmental conditions and associated fire regimes in the Central Coast bioregion, we subjected the subsection data in Table 14.1 (excluding subsection area) to principal components analysis (PCA) using the correlation matrix of the 12 variables. We included modern fire history (Table 14.1, variable 11) in the analysis because, although the modern fire history differs considerably from the historic regimes, the modern pattern of fire occurrence is still highly correlated with environmental factors such as vegetation, climate, land use, and topography and this pattern is most pertinent to current management considerations.

Subsection scores for the first two PCA axes, which account for 33% of the total variance, revealed four geographically and environmentally distinctive clusters (Fig. 14.3 and Map 14.5). We refer to these subregions as: (1) developed plains, valleys, and terraces, (2) the Santa Cruz Mountains, (3) the Santa Lucia Ranges, and (4) the Interior Coast Ranges. The factor loadings in PCA axes 1 and 2 (shown as arrows in Fig. 14.3) can be used to interpret the scores for each subsection. For example, the cluster of subsections with low scores in PCA axis 2 (Subregion 1, as described below) are those with high urban or cropland areas and a small percentage of the region in native vegetation types like blue oak woodland.

The first subregion (developed plains, valleys, and terraces) consists of flat areas dominated by urban and agricultural land use and low fire frequency. There are three disjunct areas including the Santa Maria Valley; the Watsonville Plain/Salinas Valley; and the San Francisco Bay peninsula, bay flats, and East Bay Terraces. Overall, 20% of the Central Coast region has been converted to urban or agricultural uses (California Department of Forestry and Fire Protection Multi-source landcover data, 2002, v.2, http://frap.cdf.ca.gov/data/frapgisdata/select.asp).

Of the remaining subregions, the Santa Cruz Mountains Subregion is distinctive in combining high rainfall, high




MAP 14.2. Isohyets of mean annual precipitation interpolated from weather station data for the years 1961–1990. (See Daly et al. [1994] for a description of the interpolation method.)

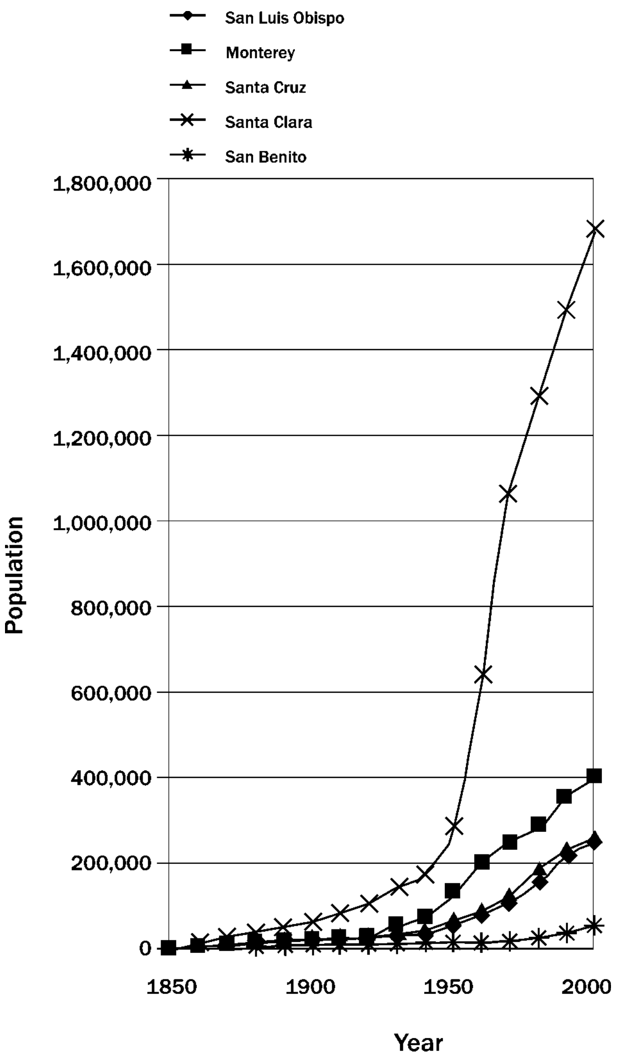



FIGURE 14.2. Population trends for selected counties of the Central Coast bioregion. (From California Department of Finance Demographic Research Unit, "Historical Census Populations of California State, Counties, Cities, Places, and Towns, 1850–2000," http://www.dof.ca.gov/HTML/DEMOGRAP/Histtext.htm.)

relief, low fire occurrence, and extensive areas of Douglas-fir and coast redwood forests.

The Southern Coastal, North Coastal, and Interior Santa Lucia Ranges form a distinctive subregion characterized by extreme ruggedness, moderate rainfall and continentality, extensive shrublands, montane hardwood forests and mixed hardwood-conifer forests, and a high occurrence of wildfire.

The Interior Coast Ranges are characterized by moderate relief, low rainfall, high summer temperatures, extensive grasslands, and intermediate wildfire frequency. Two ecological subsections—the East Bay Hills–Mount Diablo and the Leeward Hills—are intermediate in character between the Santa Cruz Mountains and the Interior Coast Ranges (Fig. 14.3). However, rather than create a separate subregion, we combined them with the interior subsections.

These four subregions provide a useful construct for comparing and contrasting fire regimes in different areas and plant communities of the Central Coast bioregion. Given the long history of cultivation in developed plains, valleys, and terraces, it is not possible to reconstruct the fire regimes of urban and agricultural valleys except in the broadest sense. We provide separate treatments of the fire history, modern fire regimes, and plant communities in the remaining three ecological subregions: the Santa Cruz Mountains, the Santa Lucia Ranges, and the Interior Coast Ranges. We describe the fire ecology and plant community–fire regime interactions of selected community species and community types associated with the Santa Lucia Ranges. We do not provide such descriptions for the other subregions because the relevant species and community types are covered in other chapters and/or because of the lack of scientific research to support such an analysis.

## Santa Cruz Mountains Subregion

Major ecological zones include: (1) coastal prairie and coastal sage scrub, (2) coast redwood–Douglas-fir and coast redwood–mixed evergreen forests, and (3) chaparral and oak woodland. Roughly 12% of the Santa Cruz Mountains subregion has been converted to urban and agricultural uses.

The coastal prairie and coastal scrub zone is most extensive below 300 m (975 ft) elevation between Point Año Nuevo and Pillar Point. Characteristic species include coyotebrush *(Baccharis pilularis)*, seaside woolly sunflower *(Eriophyllum staechadifolium)*, hairy brackenfern *(Pteridium aquilinum* var. *pubescens)*, tufted hairgrass *(Deschampsia cespitosa* ssp. *Holciformis)*, and California oatgrass *(Danthonia californica)*.

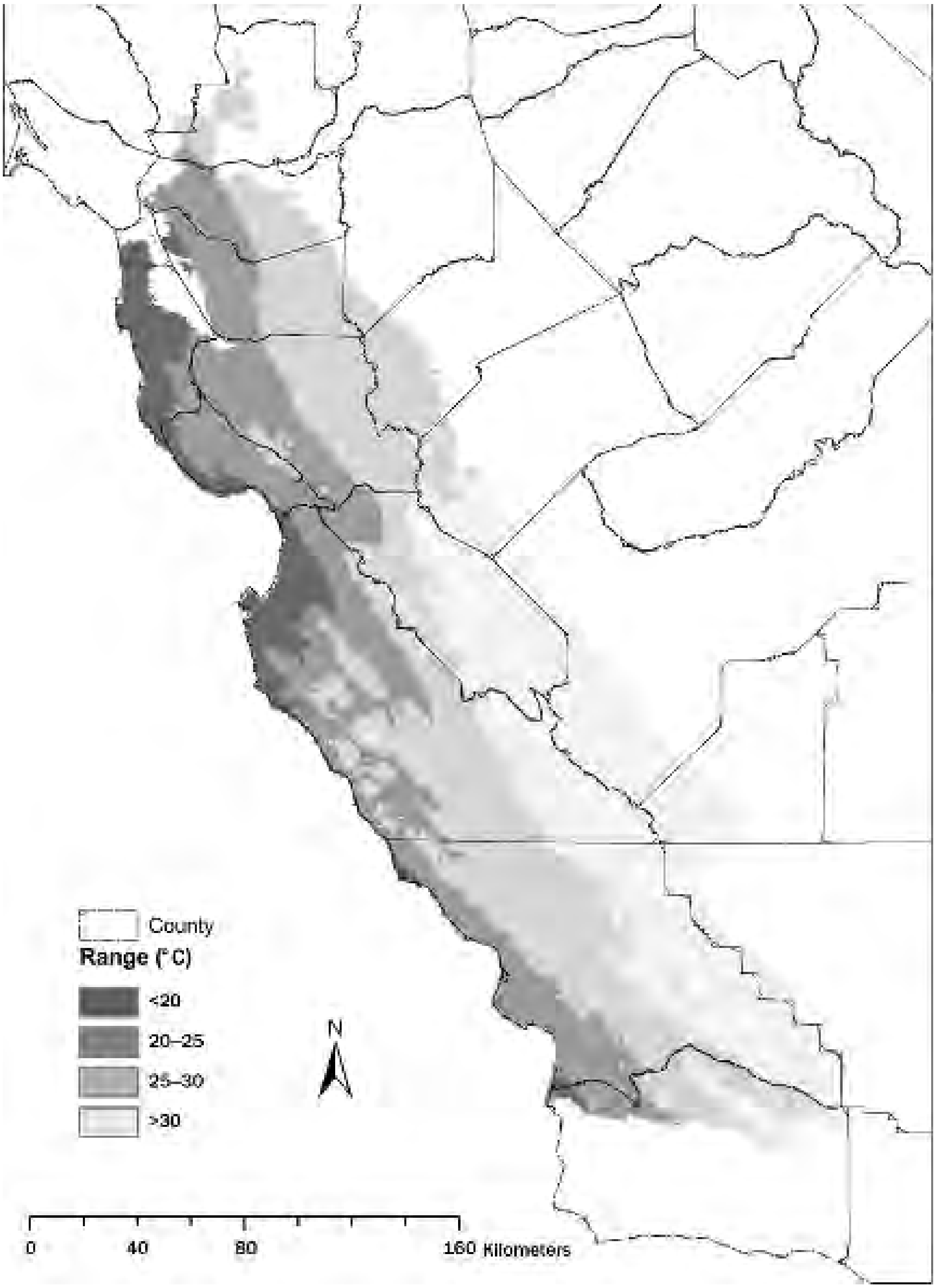
Coast redwood–Douglas-fir and coast redwood–mixed evergreen forests cover many slopes of the Santa Cruz Mountains above 300 m (975 ft) and are the most widespread vegetation types in this subregion. Coast redwood is more common on the western slopes and in more mesic sites. Mixed evergreen forests of tan oak *(Lithocarpus densiflorus)*, coast live oak *(Quercus agrifolia)*, Pacific madrone *(Arbutus menziesii)*, and California bay *(Umbellularia californica)* often occur on drier sites in topomosaics with coast redwood–Douglas-fir forests, and become more widespread in the more interior portions of the Santa Cruz Mountains.

Patches of chaparral and oak woodland are scattered throughout the subregion on xeric sites but also form an extensive zone below 600 m (1950 ft) along the eastern interior edge of the Santa Cruz Mountains. Characteristic species include chamise *(Adenostoma fasciculatum)*, buck brush *(Ceanothus cuneatus* var. *cuneatus)*, coast live oak, and valley oak *(Quercus lobata)*.

### Overview of Historic Fire Occurrence

#### PREHISTORIC PERIOD

Surprisingly little fire history research has been conducted in the Santa Cruz Mountains. As a result, we rely heavily on the



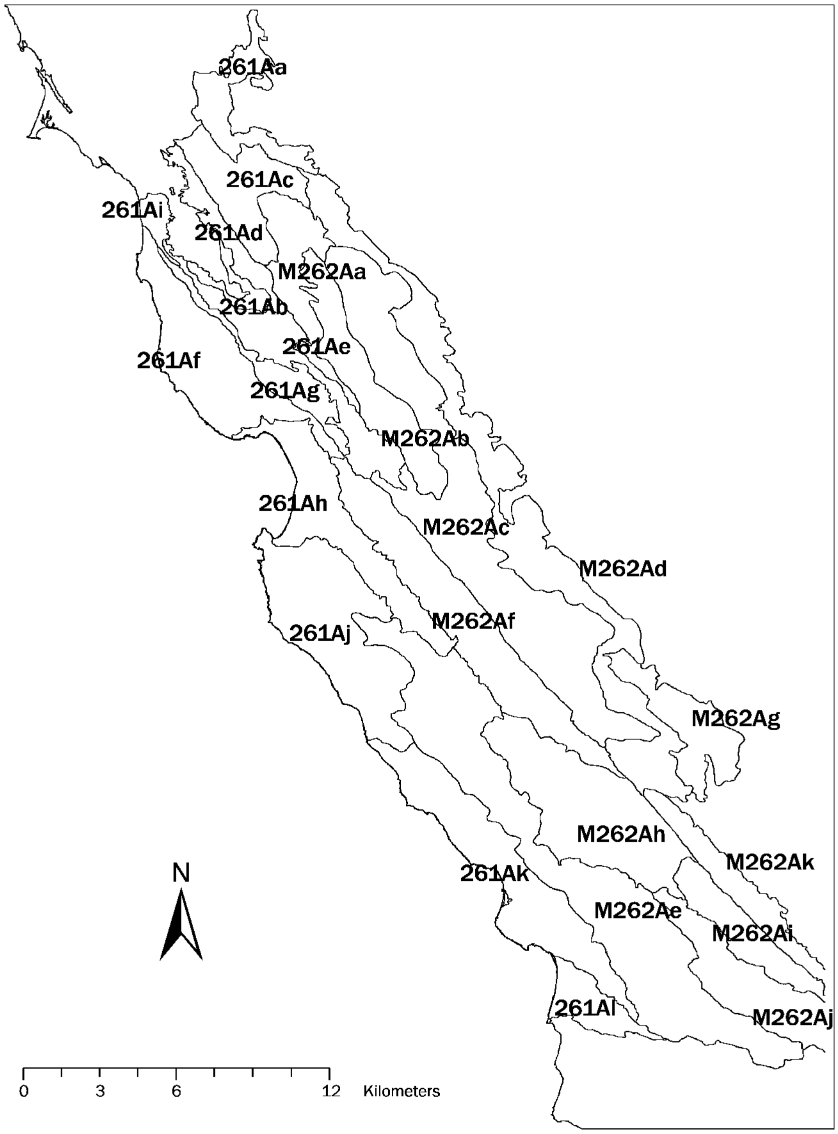

MAP 14.3. Mean annual temperature range in degrees centigrade (From DAYMET US Data Center, http://www.daymet.org/; see Thornton et al. (1997) for details of the method.)

TABLE 14.1

Ecological characteristics of the 23 subsections of the central coast bioregion

| Zone / Subsection (Code) | Area (sq. km) | Annual ppt (1) | Ann. Temp. Range (2) | August Max Temp. (3) | Chaparral (4) | Crop (5) | Grassland (6) | Blue oak woodland (7) | Redwood-Douglas Fir (8) | Montane Hardwood–Mixed Hardwood Conifer(9) | Urban (10) | % Burned (11) | Relief (12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Developed Valleys and Coastal Areas | | | | | | | | | | | | | |
| 1. East Bay Terraces and Alluvium (261Ad) | 505 | 27.08 | 27.54 | 26.74 | 0.00 | 1.38 | 1.49 | 0.02 | 0.00 | 0.00 | 94.51 | 0.18 | 2.48 |
| 2. San Francisco Peninsula (261Ai) | 195 | 26.67 | 16.91 | 23.03 | 3.92 | 0.23 | 1.34 | 0.03 | 0.00 | 0.00 | 91.92 | 3.78 | 7.73 |
| 3. Bay Flats (261Ab) | 272 | 19.52 | 21.90 | 26.91 | 0.00 | 1.10 | 1.30 | 0.00 | 0.00 | 0.00 | 80.63 | 0.00 | 0.79 |
| 4. Santa Clara Valley (261Ae) | 1180 | 19.79 | 23.43 | 27.66 | 0.05 | 27.10 | 13.67 | 0.00 | 0.00 | 0.00 | 57.70 | 0.69 | 3.08 |
| 5. Watsonville Plain–Salinas Valley (261Ah) | 1622 | 20.64 | 20.87 | 25.39 | 3.24 | 55.92 | 10.54 | 0.78 | 1.14 | 0.00 | 15.88 | 0.79 | 5.15 |
| 6. Santa Maria Valley (261Al) | 620 | 21.41 | 20.98 | 25.65 | 7.08 | 45.91 | 10.83 | 4.14 | 0.00 | 0.33 | 19.16 | 6.31 | 3.72 |
| Santa Cruz Mountains | | | | | | | | | | | | | |
| 7. Santa Cruz Mountains (261Af) | 1995 | 38.42 | 20.25 | 23.50 | 21.07 | 3.02 | 7.16 | 0.44 | 36.04 | 0.65 | 8.88 | 2.60 | 24.72 |
| Santa Lucia Ranges | | | | | | | | | | | | | |
| 8. North Coastal Santa Lucia Range (261Aj) | 2522 | 37.41 | 22.61 | 23.63 | 42.98 | 0.19 | 9.98 | 0.12 | 2.38 | 10.83 | 2.77 | 51.59 | 34.50 |
| 9. Interior Santa Lucia Range (M262Ae) | 4974 | 23.92 | 27.50 | 28.62 | 44.15 | 4.57 | 19.26 | 2.14 | 0.00 | 1.54 | 0.91 | 40.79 | 20.62 |
| 10. South Coastal Santa Lucia Range (261Ak) | 2257 | 30.23 | 23.49 | 26.22 | 22.77 | 4.69 | 31.45 | 2.11 | 0.17 | 6.67 | 4.29 | 27.87 | 21.11 |
| Interior Coast Ranges | | | | | | | | | | | | | |
| 11. Suisun Hills and Valley (261Aa) | 889 | 23.68 | 26.63 | 30.52 | 0.15 | 7.32 | 47.86 | 0.64 | 0.00 | 1.01 | 33.97 | 6.84 | 10.28 |
| 12. East Bay Hills–Mount Diablo (26lAc) | 1190 | 21.56 | 23.87 | 28.04 | 11.82 | 0.15 | 24.76 | 0.12 | 0.38 | 1.37 | 35.08 | 4.25 | 19.36 |
| 13. Eastern Hills (M262Ad) | 3567 | 15.45 | 31.74 | 33.09 | 3.83 | 1.00 | 83.07 | 2.97 | 0.00 | 0.00 | 2.23 | 16.58 | 16.43 |
| 14. Fremont- Livermore Hills and Valleys (M262Aa) | 985 | 18.12 | 26.14 | 29.22 | 1.11 | 5.58 | 51.59 | 2.14 | 0.00 | 0.85 | 21.27 | 2.52 | 16.55 |
| 15. Leeward Hills (261Ag) | 653 | 28.55 | 23.61 | 26.18 | 16.44 | 2.99 | 14.77 | 0.17 | 1.99 | 0.30 | 25.12 | 10.41 | 23.44 |
| 16. Diablo Range (M262Ac) | 4739 | 19.58 | 32.51 | 31.91 | 19.74 | 0.77 | 33.42 | 25.98 | 0.00 | 0.55 | 0.35 | 14.16 | 24.48 |
| 17. Western Diablo Range (M262Ab) | 1352 | 19.33 | 28.66 | 29.15 | 8.95 | 0.78 | 32.72 | 10.98 | 0.00 | 3.90 | 0.34 | 7.98 | 29.11 |
| 18. Gabilan Range (M262Af) | 2424 | 20.15 | 29.10 | 30.05 | 20.49 | 1.34 | 49.01 | 0.55 | 0.00 | 0.51 | 0.19 | 14.77 | 17.29 |
| 19. Kettleman Hills and Valleys (M262Ag) | 1055 | 11.09 | 31.83 | 34.40 | 0.00 | 38.04 | 52.88 | 0.06 | 0.00 | 0.00 | 6.22 | 3.46 | 4.02 |
| 20. Paso Robles Hills and Valleys (M262Ah) | 2574 | 21.75 | 29.82 | 31.13 | 2.81 | 7.01 | 73.65 | 0.75 | 0.00 | 0.07 | 2.55 | 7.51 | 8.36 |
| 21. Temblor Range (M262Ak) | 939 | 15.03 | 32.31 | 32.52 | 2.19 | 0.08 | 72.97 | 0.04 | 0.00 | 0.00 | 0.28 | 3.72 | 17.81 |
| 22. Carrizo Plain (M262Ai) | 857 | 13.96 | 31.27 | 31.87 | 0.11 | 0.01 | 88.27 | 0.04 | 0.00 | 0.00 | 0.01 | 4.26 | 4.35 |
| 23. Caliente Range–Cuyama Valley (M262Aj) | 1462 | 15.72 | 30.39 | 30.79 | 21.82 | 7.37 | 44.78 | 0.82 | 0.00 | 0.38 | 1.22 | 13.62 | 13.37 |

NOTE: Subsections are grouped into four zones for the purpose of describing the fire ecology of the region. Subsection names and codes are based on Miles and Goudy (1997). Climate statistics are based on 1 km climate grids (Thornton and Running 1997). Percentages of the subsection in different land use and land cover types are based on 100-m resolution multi-source land cover data (California Wildlife Habitat Relationship system) obtained from the California Department of Forestry and Fire Protection (CDF&FP).




MAP 14.4. Ecological subsections of the study region as defined by Miles and Goudey (1997). See Table 14.1 for subsection names and descriptions.

study by Greenlee and Langenheim (1990) and on the reconstruction of fire history in Douglas-fir *(Pseudotsuga menziesii)* and coast redwood *(Sequoia sempervirens)* forests to the north at Point Reyes National Seashore by Brown et al. (1999).

Based on a simple model of lightning ignitions and fire spread, Greenlee and Langenheim (1990) concluded that, in the absence of aboriginal burning, coast redwood forests of the Santa Cruz Mountains would experience a mean fire interval of around 135 years while mixed evergreen forests might burn every 30 to 135 years. Being warmer and drier, oak woodland and chaparral environments were predicted to have shorter mean fire intervals of 10 to 30 years, while the interval between fires in coastal prairie and coastal sage scrub varied from 1 to 15 years. Given the documented low incidence of lightning in the region, these return intervals are probably too short for the coastal communities.

It is now widely accepted that Native Americans used fire to manage vegetation in central coastal California. Native Americans occupied the entire coast at densities averaging one to three persons per $km^2$ (Keeley 2002b). The Ohlone (Castanoans) inhabited an area from San Francisco to Point Sur and regularly burned coastal vegetation to stimulate the seed production of preferred species (Lewis 1973, Gordon 1979). Greenlee and Langenheim (1990) argued that aboriginal burning increased fire frequency and reduced the mean fire interval in coast redwood forests from 135 years to 17–82 years. In contrast to these findings, fire histories from coast redwood–Douglas-fir forests at Point Reyes and the Santa Cruz Mountains suggest a higher pre-Columbian mean fire interval of 8 to 12 years (Brown et al. 1999, Stephens and Fry 2005).

### HISTORIC PERIOD

The arrival of the Spanish in the late 1700s brought lasting changes in land use and fire regimes over much of the bioregion. In the Santa Cruz Mountains, prohibitions on burning, population decline, and cattle grazing during the Mission era of the late eighteenth and early nineteenth centuries reduced

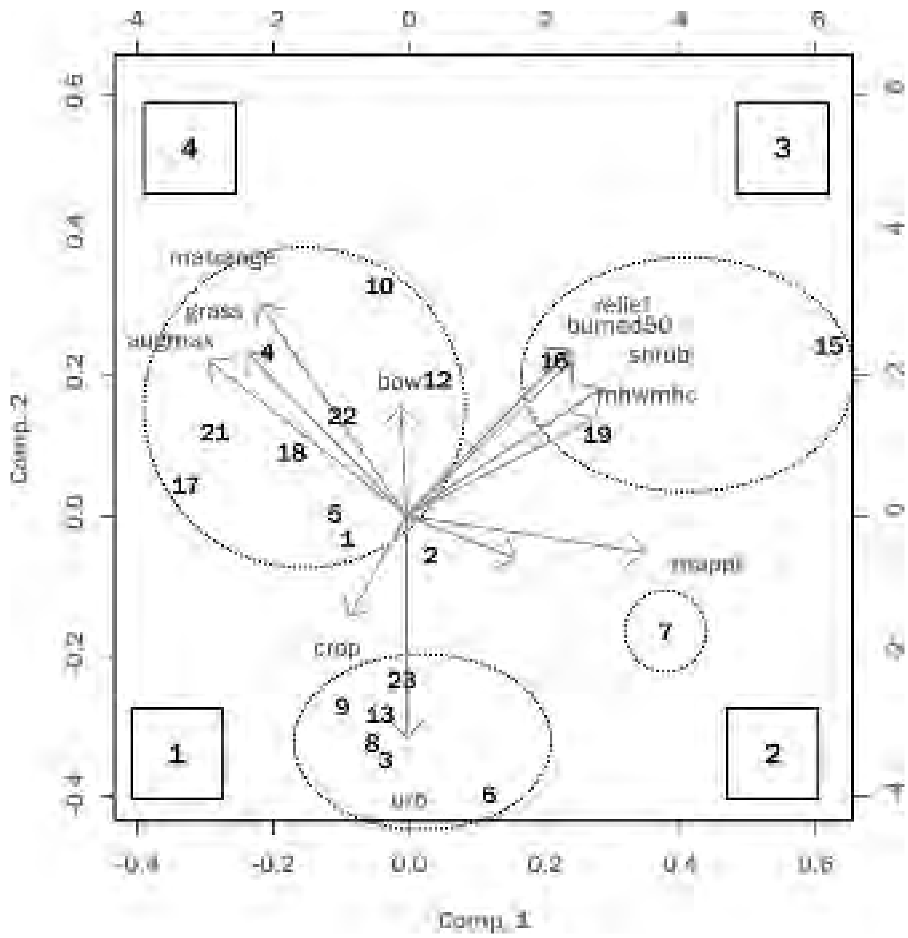



FIGURE 14.3. Scatterplot of PCA scores for 23 ecological subsections (see Table 14.1 for number codes). Loadings of original variables are portrayed as arrows. Variables include topographic relief (relief), mean annual precipitation (mappt), mean annual temperature range (matrange), august maximum temperature (augmax), percentage cropland (crop), percentage urban (urb), percentage grassland (grass), percentage shrubland (shrub), percentage blue oak woodland (bow), percentage montane hardwood/montane hardwood conifer (mhwmhc), and percentage of the subsection that burned at least once since 1950 (burned50). Fire subregions are enclosed in ellipses and numbered (boxes) to correspond with Map 14.5.

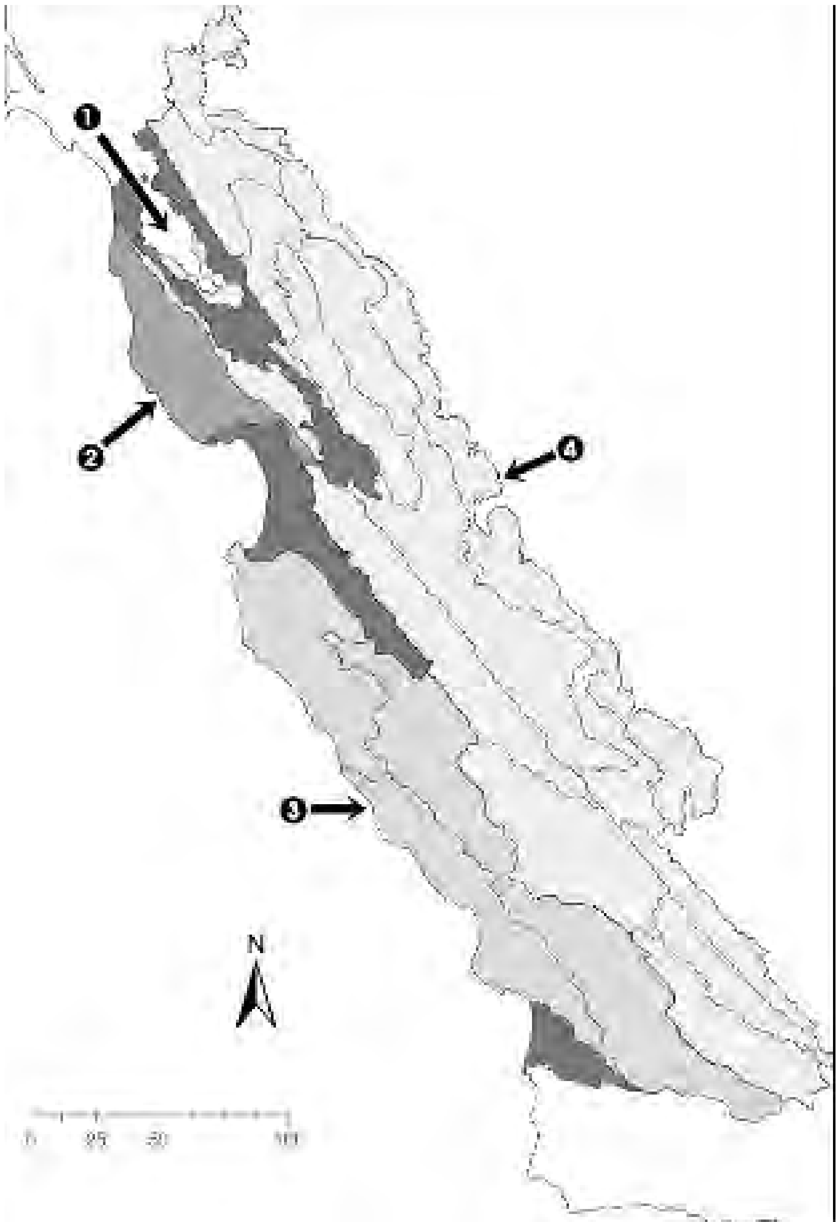
fire use by the Castanoans. Using a combination of modeling, newspaper accounts, and fire scars, Greenlee and Langenheim (1990) concluded that over the course of the nineteenth century and early twentieth century, fire frequency decreased in coastal vegetation types like coastal prairie and coastal sage scrub to a mean fire interval of 20 to 30 years and decreased in oak woodlands from a pre-Columbian mean fire interval of 1 to 2 years to 50 to 75 years. At the same time, they concluded that fire frequency increased in chaparral and coast redwood forests to 7 to 29 years and 20 to 50 years, respectively, probably due to fires that escaped from burning of logging slash as well as deliberate burning to convert chaparral to pasture and farmland. Logged areas of the Santa Cruz Mountains likely burned at least once and perhaps as many as three times during the late nineteenth and early twentieth century. Fire scar data from coast redwood forests to the north also show a late nineteenth century increase in fire frequency, but suggest a much shorter mean fire interval of 4 to 12 years (Brown et al. 1999, Stephens and Fry 2005) compared with the 20 to 50 years of Greenlee and Langenheim (1990).

#### CURRENT PERIOD

Since 1930, fire suppression has successfully controlled most wildfires in the Santa Cruz Mountains. Between 1929 and 1979, 3,765 recorded fires burned only 21,500 ha (53,105 ac), and 92% of the fires burned less than 4 ha (10 ac) (Greenlee and Langenheim 1990). One of the largest recorded fires burned 6,400 ha (15,808 ac) over a seven-day period in 1948 (Stephens et al. 2004). Fire suppression has reduced fire frequency in all major vegetation types, but most dramatically in coastal prairie, where fire now rarely, if ever, occurs. Their estimated mean fire intervals for chaparral/coastal sage scrub, oak woodland, and mixed evergreen forest are on the order of 150 to 250 years. Mean fire interval in a Monterey pine (*Pinus radiata*) forest varied from 40 to 60 years. Recent burning has been most prevalent in coast redwood forests, but even in that type the mean fire interval is estimated to be 100 to 150 years. Brown et al. (1999) report a similar pattern from Point Reyes National, where surface fires in coast redwood and Douglas-fir forests essentially ceased after 1945.

### Major Ecological Zones

*Coastal Prairie and Coastal Sage Scrub* Unfortunately, the fire ecology and plant community–fire regime interactions of coastal prairie and Diablan coastal sage scrub have received little formal study. There is little doubt that fire frequency is much lower today than in prehistoric and historic




MAP 14.5. Aggregation of ecological subsections into ecological zones based on climate, topography, land use, vegetation, and post-1950 fire history. Subsection boundaries are drawn.

eras. Like other grassland and coastal scrub ecosystems, these communities are grazed and are also heavily invaded by exotic weeds. Hatch et al. (1999) examined the response of native grasses to fall burning and grazing in coastal prairie at Pomponio State Beach in the northwestern subregion and did not observe a significant effect of a single burn on California oatgrass or needlegrasses. Native species increased slightly under moderate grazing compared to ungrazed controls. The authors note that these responses are different from those obtained from grasslands at inland sites and suggest that fire and grazing exclusion have limited value for restoring coastal prairie.

*Coast Redwood–Douglas-fir and Mixed Evergreen Forest Zone* Stuart and Stephens (this volume) describe the fire ecology and interactions between fire regime and community dynamics for coast redwood forest in northwest California. They note that the degree of fire dependence in this community type should be viewed as a continuum and that more southern and drier occurrence of the type may be more fire prone and fire dependent.

They also review the fire ecology and regime characteristics of Douglas-fir–tanoak forests, which bear a close resemblance to the mixed evergreen forests of the Santa Cruz Mountains. Douglas-fir is less prevalent in the mixed evergreen forests of the Santa Cruz Mountains, and we would expect these forests to be somewhat drier and more fire prone during the summer months than those to the north. As noted above, fire suppression has greatly reduced fire occurrence in both coast redwood–Douglas-fir and mixed evergreen forests compared with prehistoric and historic eras.

FIGURE 14.4. Grassland, chaparral, and coastal scrub mosaic in the fooothill and lower montane zones of the southern Santa Lucia Ranges subregion. View is looking northwest from Cuesta Grade toward Morro Bay, San Luis Obispo County. (Photo by Christopher Cogan.)

*Chaparral and Oak Woodland Zone* Keeley (this volume) discusses the fire ecology of chaparral vegetation and Wills (this volume) discusses the fire ecology of foothill oak woodland and grassland. As noted previously, no large wildfires have occurred in this zone since at least 1950, and Greenlee and Langenheim (1990) estimate that the mean fire interval here is now greater than 150 years. This contrasts sharply with chaparral communities in the other subregions of the Central Coast bioregion and in the South Coast California bioregion, where large wildfires still occur despite intense suppression efforts. This may reflect the patchier distribution of chaparral vegetation in the eastern Santa Cruz Mountains, the somewhat wetter and cooler prevailing climate, or the greater accessibility of the area to suppression forces.

### Santa Lucia Ranges Subregion

Viewed along a coast-to-interior transect, major ecological zones of this subregion include: (1) coastal plain and foothills, which support coastal prairie, annual grassland, coastal sage scrub, maritime chaparral, coast live oak forests, and closed cone pine forests; (2) a lower montane zone dominated by topo-mosaics of chaparral, coastal sage scrub, and coast live oak woodlands and forests, but also supporting azonal serpentine grasslands and cypress woodlands; and (3) an upper montane zone supporting mixed evergreen forests, Coulter pine forests, and mixed conifer forests. Inland valleys and the interior edge of this subregion, which are dominated by oak woodland, coastal sage scrub, and annual grasslands, comprise a fourth ecological zone that we refer to as the interior foothill zone. Additionally, roughly 5% of the Santa Lucia Ranges subregion has been converted to urban and agricultural uses (Fig. 14.4).

In the coastal plain and foothills zone, widespread alliances include California annual grasslands, coyote brush, California sagebrush *(Artemesia californica)*, blue blossom *(Ceanothus thyrsiflorus)*, and yet-to-be-described alliances of the Diablan, Franciscan, and Lucian coastal sage scrub associations. Coast live oak occurs in many coastal and foothill settings and plant communities including closed forests (typically greater than 60% crown cover), open woodlands and savannas (10%–60% crown closure with an herbaceous understory), coastal sage scrub and chaparral (Griffin 1988, Allen et al. 1991, Sawyer and Keeler-Wolf 1995, Peinado et al. 1997). Localized vegetation types of special interest include closed-cone pine forests and maritime chaparral. The former includes Bishop pine *(Pinus muricata)* forests, knobcone pine *(Pinus attenuata)* forests, and Monterey pine forests along the Monterey and Big Sur Coast. Maritime chaparral combines chamise, coast live oak, and highly localized California-lilac and manzanita species.

Vegetation of the lower montane zone includes a diverse variety of localized types but generally presents a mosaic of coastal scrub, chaparral, and oak woodland. Widespread scrub types include black sage *(Salvia mellifera)*, purple sage *(Salvia leucophylla)*, and California buckwheat *(Eriogonum fasciculatum)*. Widespread chaparral types include chamise, buck brush, and scrub oak alliances. Coast live oak is the most widespread woodland series. Sargent cypress *(Cupressus sargentii)* forests are one of the many distinctive mid-elevation community types associated with ultramafic-derived soils.

In the upper montane zone, mixed evergreen forests (oak, Pacific madrone, tan oak, California bay, big-leaf maple [*Acer macrophyllum*]) are widespread in the northern Santa Lucia Range. Hardwood-conifer forests (ponderosa pine [*Pinus ponderosa*], Coulter pine [*Pinus coulteri*], sugar pine [*Pinus lambertiana*], canyon live oak [*Quercus chrysolepis*], tan oak) are widespread in the North Coastal Santa Lucia Ranges at the highest elevations (Griffin 1975, 1979). Common single-species alliances include canyon live oak, California bay, tan oak, and Coulter pine.

Santa Lucia fir forests are patchily distributed at mid to high elevations, mainly in the watersheds of the Big Sur, Little Sur, and Upper Carmel Rivers in Monterey County. High elevation coastal forests include ponderosa pine and sugar pine alliances. In the southern Santa Lucia Mountains, mixed evergreen forests, conifer-hardwood forests, and montane conifer forests become highly localized in their distributions. Here Coulter pine/montane chaparral is the most abundant conifer type, especially in the La Panza Range (Borchert et al. 2004).

The interior foothill zone includes extensive blue oak and valley oak woodland, annual grassland, chamise chaparral, and California buckwheat scrub.

## Overview of Historic Fire Occurrence

### PREHISTORIC AND HISTORIC PERIODS

Analysis of charcoal particles in varved sediments from the Santa Barbara Basin from A.D. 1425 to 1985 furnishes the most detailed, long-term fire history for the southern Santa Lucia Ranges and western Transverse Ranges to the south (Byrne et al. 1977, Mensing et al. 1999). Using a significant correlation between the large charcoal (more than 3,750 $\mu m^2$) accumulation rate and total burned area on the coastal Santa Barbara Ranger District of Los Padres National Forest, Mensing et al. (1999) recorded 23 fires burning more than 20,000 ha (49,400 ac) in a 560-year record. The average interval between fires was 24 years (SD ± 18.4, n = 22) with a range of 5 to 75 years. Remarkably, the mean interval between large fires changed little during four very different periods: the Native American (prior to 1792), Spanish-Mexican (1792–1848), Anglo (1849–1929) and Recent (1930–present). Mensing et al. (1999) also compared a time series analyses of tree-ring data from bigcone Douglas-fir *(Pseudotsuga macrocarpa)* (Haston and Michaelsen 1994) with the varve record and found large fires to be most common in the early years of multi-year drought periods at the end of wet periods that perhaps resulted in higher fuel loads.

The fire history depicted in the varve sediments likely only applies to the southern Santa Lucia Mountains from Santa Barbara north to San Luis Obispo, or possibly to Morro Bay. Still, large fires periodically have burned along the coast of the northern Santa Lucia Mountains, as evidenced by the Marble Cone fire (72,500 ha [179,075 ac]) in 1977 and Kirk Complex (35,100 ha [86,697 ac]) in 1999, both caused by lightning. Even before fire suppression began around 1910, a 20,000-ha (49,400-ac) human-caused fire burned in 1903 and a 60,000-ha (148,200-ac) fire occurred in 1906 (Henson and Usner 1993). In the late 1800s, reports of huge fires were common in newspapers and government reports (Griffin 1978a).

Although fires larger than 20,000 ha (49,400 ac) probably have a long history in this region, prehistoric mudflows in the Big Sur River (Jackson 1977) suggest that the average interval between large fires may have been longer than the interval gleaned from varve cores in the Santa Barbara region. The two most recent mudflow events both coincided with large fires in watersheds of the Big Sur River drainage. Assuming such mudflows have followed all large fires, then the mean interval between fires over the period 1370 A.D. to 1972 A.D. can be estimated as 75 years (SD ± 19.7, n = 8). However, fire recurrence estimates from varve sediments and mudflows are not directly comparable because the varve sediments represent a much larger area than watersheds of the Big Sur River.

The extent of burning by Native Americans is unknown but was probably sufficient to alter pre-Columbian fire regimes and vegetation patterns over a significant part of the bioregion. The Esselen Indians occupied a comparatively small area from Point Sur to Big Creek and inland to the Salinas River. South and east of the Esselens, the Salinians reached San Carpoforo Creek. Unfortunately, we know little about fire use by either group (Henson and Usner 1993).

Further south, burning likely occurred not only in coastal prairie and oak woodlands, but also in chaparral and coastal sage scrub (Keeley 2002). South of the Salinians, the Chumash territory stretched from the Santa Maria River to the Santa Clara River and east to the upper Cuyama Valley (Keeley 2002b). Using diaries and journals of early explorers and clerics, Timbrook et al. (1982) documented that the Chumash, like the Ohlone to the north, regularly employed burning to encourage the growth of bulbs, green shoots, and seeds of herbs like chia *(Salvia columbariae)* and Brewer's redmaids *(Calandrinia breweri)*. Frequent burning could have converted many areas of coastal sage scrub and chaparral to grasslands, although there were certainly large areas that, due to their ruggedness and remoteness, were little affected by Native American burning (Keeley 2002). With the advent of the Mission Era, fire frequency likely was reduced in coastal plain and foothill environments.

### CURRENT PERIOD

Although separated by less than 75 km, the northern Santa Lucia Ranges and Santa Cruz Mountains provide a dramatic contrast in modern fire histories. Fire is much more widespread in the Santa Lucia Ranges, where roughly one quarter of the region has burned at least once since 1950 (Table 14.1). Furthermore, fires that have occurred in recent times in the Santa Lucia Ranges are much larger than are those in the Santa Cruz Mountains. The largest modern fires in the Santa Cruz Mountains, including an 8,000-ha (19,760-ac) burn in 1948, the 1,320-ha (3,260-ac) Lincoln Hill fire in 1962, and the 5,314-ha (13,125-ac) Lexington fire of 1985 (which mainly burned east of the Santa Cruz Mountains in the Leeward Hills), are an order of magnitude smaller than the largest fires in the northern Santa Lucia Ranges.

Relatively detailed records of twentieth century fires on Los Padres National Forest have been analyzed by Davis and Michaelsen (1995), Mensing et al. (1999), and Moritz (1997, 2003). A large fraction of area burned in the Santa Lucia Ranges since 1900 can be attributed to a few very large fires. Most of these large fires have been human-ignited (except the aforementioned Marble Cone and Kirk Complex fires) and many of the large fires at the southern end of the region have

TABLE 14.2
Fire response types for important species in the coastal woodlands and forests of the lower montane zone in the coastal plain and foothills subregion

| *Lifeform* | *Type of Fire Response* | | | *Species* |
|---|---|---|---|---|
| | Sprouting | Seeding | Individual | |
| Conifer | None | Fire stimulated release of seeds from serotinous or partially open cones; serotiny varies considerably species to species | Killed | Knobcone pine, Sargent cypress, Coulter pine, Bishop pine, Monterey pine |
| | None | None | Killed; survives in fire-proof locations | Santa Lucia fir |
| Hardwood | Fire stimulated | None | Top-killed/survive; coast live oak crown sprouts from epicormic buds | Coast live oak, interior live oak, Pacific madrone, tan oak, big-leaf maple, California bay |

spread under severe weather conditions of high temperature and winds (Davis and Michaelsen 1995; Moritz 1997, 2003).

Based on analyses of Los Padres fire history data, Moritz (1997, 2003) concluded that fire hazard in the Santa Lucia Ranges is not significantly related to fuel age but is controlled instead by extreme weather events. A combination of rugged terrain and poor access into remote wilderness areas has limited the ability of firefighting agencies to control fire spread in these weather conditions, and, despite an improved suppression effort, there does not seem to be a temporal trend in large fire frequency in this region (Moritz 1997). However, the introduction of fixed-wing aircraft and helicopters after 1950 has proved effective in reducing fire spread under more moderate conditions. For example, since 1950, fires between 500 and 5,000 ha (1235–12,350 ac) are less frequent than they were from 1911 to 1950 (Moritz 1997).

Los Padres National Forest fire history data have also been used to compare fire sizes in the southern ("Main") Division and the Monterey Division in the southern and northern Santa Lucia Ranges, respectively. The Main Division (which extends out of the Central Coast bioregion into the northern Southwestern bioregion) displays a higher frequency of large fires (more than 4,000 ha [9,880 ac]) than does the Monterey Division. For example, 80% of the fires in the Monterey Division are smaller than 900 ha (2,223 ac), whereas for the Main Division, 80% are less than 5,300 ha (13,091 ac) (Moritz 1997).

## Major Ecological Zones

The complex vegetation mosaics of the Santa Lucia Ranges do not lend themselves to a simple zonal vegetation classification scheme. Instead we focus on those species and community types that are characteristic of this subregion and whose fire ecology has been formally investigated. Unfortunately, most widespread chaparral and coastal sage scrub community types have received practically no study in this region, so we refer the reader to the chapter by Keeley (this volume) for a discussion of these types. Similarly, we are unable to report on the fire ecology of the mixed evergreen forests of the upper montane zone. For a treatment of annual grassland and blue oak woodland of the inland foothill zone, we refer the reader to the chapters by Wills (this volume).

Here we review the ecology of several species and community types that, with the exception of coast live oak, are characteristic of the region but are relatively localized. In the coastal plain and foothills zone we highlight Bishop pine, Monterey pine, maritime chaparral, and coastal live oak forests and woodlands. Of the many species and community types characteristic of the lower montane zone, we discuss knobcone pine and Sargent cypress. Coulter pine is the only species and community type discussed that is characteristic of the upper montane zone.

## Bishop Pine

### FIRE ECOLOGY

Bishop pine forms distinct northern (northern Bishop pine) and southern (southern Bishop pine) varieties that diverge from one another at Monterey (Millar 1983). Fire research on Bishop pine has focused entirely on the northern borealis variety. Bishop pine is nonsprouting and moderately serotinous (Keeley and Zedler 1998) (Table 14.2).

Sugnet (1981) examined the age structure of six Bishop pine stands along the Inverness Ridge in Point Reyes National Seashore. Three stands were even-aged, showing a single pulse of seedling recruitment that he traced to earlier fires. Indeed, post-fire seedling establishment of Bishop pine can be prolific (Ornduff and Norris 1997). After a 1996 fire on Inverness Ridge, B. Holzman (personal communication) recorded an average of 26 Bishop pine seedlings/$m^2$ (2.4 seedlings/$ft^2$), some of which had reached heights of 1.2 m (3.9 ft) by the following year. Even-aged stands, however, did not always result from high-intensity fires.

Sugnet (1981) also observed near-complete mortality in a stand that was subject to a low-intensity backing fire. Even though Bishop pine has thick bark and is resistant to most surface fires, the high mortality was due to basal girdling by prolonged, smoldering combustion in the deep (up to 25 cm [10 in]) litter layer that develops in stands older than 40 years. Thus, while even-aged stands result primarily from high-intensity fires, lethal ground fires also can induce an even-aged structure. Two stands Sugnet (1981) examined were multi-aged but the youngest cohorts were not associated with past fires, indicating that seedling establishment had taken place beneath an older cohort of trees. Bishop pine does not require fire to free seeds from the cones. Cones also open on hot days and seeds released in this way may establish in the understory.

#### FIRE REGIME–PLANT COMMUNITY INTERACTIONS

Keeley and Zedler (1998) proposed a comprehensive framework for understanding the evolution of the major life history strategies of species in the genus Pinus. Schwilk and Ackerly (2001) have elaborated further on the strategy that has selected for flammable, serotinous species. They postulated that in a regime of frequent, high-intensity fires of large patch size, pines would evolve a suite of "fire-embracing" traits; that is, traits that increase or promote flammability. These traits include serotiny, thin bark, short height at maturity (because of slow growth on low-productivity sites), a lack of self-pruning, more flammable foliage, a relatively early age of cone production, and limited seed dispersal.

Several lines of evidence suggest that within-species variation in Bishop pine may reflect selection for a number of fire-embracing traits along north-to-south and maritime-to-interior gradients of varying fire regimes. Common-garden studies of Bishop pine, for example, have shown that southern Bishop pine populations have genetically slow growth (Millar 1986)—a trait that increases the likelihood that fire will carry from the understory into the tree canopy (Keeley and Zedler 1998).

Serotiny, another fire-embracing characteristic, increases from the northern Bishop pine populations to the southern Bishop pine populations (Duffield 1951). Compared to the southern Bishop pine populations, the northern Bishop pine populations burn relatively infrequently and average fire size tends to be much smaller (Greenlee and Langenheim 1990; also this chapter). Even within the northern Bishop pine variety, Millar described an uncharacteristically high degree of serotiny in five Bishop pine populations growing inland of coastal Inverness populations. In growth form and degree of serotiny, inland populations more closely resembled those of the southern Bishop pine variety. Compared to coastal forests, inland stands had multiple whorls of serotinous cones that remained closed for longer periods of time. Furthermore, stands were growing in or near flammable chaparral and therefore were more likely to burn in crown fires. Millar (1986) speculated that the increased serotiny of the inland populations may be a consequence of the relatively frequent stand-replacing fires in the warmer, drier interior. It would be interesting to know if other traits in Bishop pine such as bark thickness, self-pruning, foliage flammability, age of cone production, and seed dispersal also vary systematically with the north–to-south change in fire regime.

### Monterey Pine

#### FIRE ECOLOGY

Of the three members of the closed-cone pines, Monterey pine is the most restricted in its distribution and also is the least variable genetically (Millar et al. 1988). Like Bishop pine, Monterey pine is a moderately serotinous nonsprouter. Also like Bishop pine, seed release is highest following fires but some cones also open every year, providing continuous seed input for inter-fire regeneration (Table 14.2).

#### FIRE REGIME–PLANT COMMUNITY INTERACTIONS

There are no long-term fire ecology studies of Monterey pine within its native distribution. In 1994, White (1999) revisited 38 pine stands on the Monterey Peninsula that he had first sampled from 1965 to 1966. He excluded 19 of the original samples for various reasons: partial or complete logging, urban conversion, etc. Two stands burned completely in a 1987 fire. The 19 stands he resampled were highly heterogeneous in structure. Some appeared to be even-aged—the result of high-intensity fires in the past. Others had a wide array of diameter classes indicating that, as in Bishop pine, a small percentage of seedlings in unburned stands become saplings and pole-sized trees. Thus, while seedling establishment is clearly most abundant following fire (more than 100,000 seedlings/ha [247,000 seedlings/ac]), long unburned pine stands do not convert to coast live oak forests, the most frequent understory tree, but continue to be dominated by Monterey pine (Fig. 14.5).

Stephens et al. (2004) investigated the fire history and postfire recruitment of Monterey pine north of Santa Cruz. An analysis of fire scar data revealed average mean fire return intervals of 11.2 to 20.1 years (Table 14.3). Mixed-severity fires dominated the fire regime in this area resulting in multi-aged forests with high spatial heterogeneity. Indeed, 51% of

TABLE 14.3
Fire regime characteristics for coastal shrub and woodland forests

| Vegetation type | Bishop and monterey pine | Coast live oak | Maritime chaparral |
|---|---|---|---|
| Temporal | | | |
| Seasonality | Late summer–fall | Spring/summer–fall | Spring/summer–fall |
| Fire-return interval | Medium–long | Short–medium | Truncated medium |
| Spatial | | | |
| Size | Medium–large | Small–large | Medium–large |
| Complexity | Low–moderate | Low–moderate | Low |
| Magnitude | | | |
| Intensity | Multiple | Multiple | High |
| Severity | Moderate–high | Multiple | Moderate–high |
| Fire type | Multiple | Surface | Crown |

FIGURE 14.5. Monterey pine forest understory near Cambria dominated by blackberry and poison oak. This site has not burned for many decades.

the trees in openings regenerated within 5 years of the most recent fire. In general, however, the evidence suggests that Monterey pine forests do not require periodic fire to persist on the landscape and perhaps urbanization poses the greatest threat to this species.

## Coast Live Oak Forest and Woodland

### FIRE ECOLOGY

Coast live oak is one of the most fire-resistant oaks in California (Lathrop and Osborne 1991). Coast live oak seedlings and saplings can survive relatively low-intensity surface fires (Snow 1980), although seedling mortality is undoubtedly higher during high-intensity surface fires and crown fires (Table 14.2). Adult trees exhibit a number of fire adaptations, including dense outer bark, a thick inner bark with high insulating capacity, and an ability to resprout from the base and crown following severe wildfires (Plumb 1980). Adult survival rates exceeding 95% have been documented following severe wildfire, and canopy volume may return to pre-fire levels within 5 to 10 years (Plumb 1980, Dagit 2002). Mortality rates are higher for late-season fires and for oaks growing among chaparral shrubs where fire severity is more extreme (Wells 1962, Plumb and Gomez 1983, Davis et al. 1988a).

### FIRE REGIME–PLANT COMMUNITY INTERACTIONS

Pollen records from the Santa Barbara Channel and Zaca Lake in northern Santa Barbara County indicate that coast live oak populations were relatively stable for many centuries prior to European settlement but have increased in the last quarter of the nineteenth century (Mensing 1998).

Coast live oak is widespread in grasslands and oak savannas of the region but appears to be declining in these settings due to tree removal and low recruitment of tree-sized individuals due to drought and herbivory by rodents, deer, cattle, and insects (Plumb and Hannah 1991, Callaway and Davis 1998, Parikh and Gale 1998, Dunning et al. 2003). Because of grazing and fire suppression, fires are now infrequent in this vegetation type (Table 14.3). Unfortunately, the effects of frequent fires in this vegetation, such as may have occurred prehistorically, have not been studied.

Callaway and Davis (1993) documented a shifting mosaic of four vegetation types in Gaviota State Park and on neighboring ranchlands between 1947 and 1989 (Fig. 14.6). Unburned annual grasslands were invaded by coastal sage

FIGURE 14.6. Patches of Coast live oak forest in a matrix of annual grassland on northern footslopes of the Purisima Hills, Los Alamos Valley, Santa Barbara County.

scrub, and unburned coastal sage scrub was invaded by coast live oak leading to the formation of oak woodlands. Coast live oak rarely replaced grassland directly but could invade coastal sage scrub by using the shrubs as seedling nurse plants. However, oak cover declined in oak woodlands with a grass understory, suggesting a long-term return to grasslands, presumably because oak seedlings do poorly in the understory of oak woodlands, except in the most mesic settings. In burned areas, fire slowed the transition of coastal sage scrub to oak woodlands because acorns and seedlings succumbed in fires. Grazing also slowed the transition rate to oak woodlands because it delayed the transition from grassland to coastal sage scrub. In addition to grazing and fire, transition rates also were dependent on soil types.

Coast live oak is shade tolerant (Callaway 1992) and recruits into both chaparral and coastal sage scrub on many substrates as well as into more mesic settings such as north-facing slopes and areas bordering riparian areas of central coastal California (Wells 1962, Callaway and Davis 1993, Callaway and Davis 1998, Parikh and Gale 1998). Nevertheless, high-intensity fires in shrublands probably kill most seedlings and saplings, thereby reversing any increase in oak cover that takes place during fire-free periods (Wells 1962, Callaway and Davis 1993, Van Dyke and Holl 2001). It would appear that on many sites the presence of oak woodland versus chaparral or coastal sage scrub depends on whether sufficient time has elapsed between fires for oaks to establish and grow large enough to endure high-intensity fires (Table 14.3).

In coast live oak forests, the litter layer is often deep, and perennials such as poison oak *(Toxicdendron diversilobum)*, Christmas berry *(Heteromeles arbutifolia)*, and hairy brackenfern form a discontinuous herb and shrub understory (Campbell 1980, Allen et al. 1991). For much of the year, fuel moisture of the shrubs and litter is high and conditions are not conducive to surface fire ignition and spread.

Little is known about the role of fire in coast live oak forest. Presumably it is less frequent than in adjacent shrubland and grassland community types, but when fire does occur, it is usually a high-severity, passive crown fire that burns all the foliage from the canopy. For example, in 1985 the Wheeler fire in Ventura County top-killed large areas of riparian forests composed of coast live oak, western sycamore *(Platanus racemosa)*, and white alder *(Alnus rhombifolia)*. Within the first year after fire, only 50% of the overstory oaks had resprouted at four monitored sites with the probability of sprouting positively correlated with diameter at breast height (Parikh 1989). Of the surviving oaks at one site, 29% subsequently were toppled by high winds (Davis et al. 1988b).

### Maritime Chaparral

Maritime chaparral is associated with sandy substrates in level or rolling terrain within 10–20 km (6–12 mi) of the coast. These areas are under a strong maritime climate characterized by frequent summer fog and low annual temperature range. Stands of northern and central maritime chaparral communities are scattered along the coast from northern Santa Barbara County to Sonoma County. Maritime chaparral supports many rare and endemic plants and thus has received a fair amount of scientific study, especially in recent decades as the type has been heavily reduced and fragmented by coastal residential development and military operations (Lambrinos 2000, Van Dyke and Holl 2001).

#### FIRE ECOLOGY

Maritime chaparral is usually dominated by chamise in combination with several locally endemic species of California-lilac and manzanita. In the Central Coastal biore-

TABLE 14.4
Fire response types for important species in the maritime chaparral found in the Santa Cruz and Santa Lucia ranges subregions

| | *Type of Fire Response* | | | |
|---|---|---|---|---|
| *Lifeform* | Sprouting | Seeding | Individual | *Species* |
| Hardwood | Fire stimulated | None | Top-killed /survive | Coast live oak |
| Shrub | None | Fire stimulated germination of soil-stored seed | Killed | Blue-blossom ceanothus, Purissima manzanita, Hooker's manzanita, Pajaro manzanita, Morro manzanita |
| | Fire stimulated | Fire stimulated | Top-killed/killed | Shagbark manzanita |

gion, characteristic shrub species include obligate-seeding species such as Santa Barbara ceanothus *(Ceanothus impressus)*, sand buck brush *(Ceanothus cuneatus* var. *fasciculatus)*, La Purisima manzanita *(Arctostaphylos purissima)*, Hooker's manzanita *(Arctostaphylos hookeri* ssp. *hookeri)*, sandmat manzanita *(Arctostaphylos pumila)*, Pajaro manzanita *(Arctostaphylos pajaroensis)*, Morro manzanita *(Arctostaphylos morroensis)*, and the resprouting sand mesa manzanita *(Arctostaphylos rudis)* (Griffin 1978, Davis et al. 1988a). Multi-trunked coast live oaks also may attain high cover, especially on deeper soils and at greater distances from the coast. Subshrub and herb layer diversity can be high, especially for the first five years following fire. In general, maritime chaparral communities exhibit higher plant species diversity than other chaparral community types (Davis et al. 1988a).

Many rare and endemic species of obligate-seeding California-lilac and manzanita in maritime chaparral are fire dependent (Table 14.4). Odion and Tyler (2002) observed high levels of fire-induced mortality in the soil seed bank of the endangered Morro manzanita and concluded that the species may require considerably longer than 40 years between burns in order to establish an adequate seed bank to replace adults killed during the fire.

#### FIRE REGIME–PLANT COMMUNITY INTERACTIONS

Lightning is rare along the coast and it is probably safe to assume that the fire regime of maritime chaparral has been anthropogenic for many millennia, especially given the prehistoric densities of native Americans in coastal areas supporting maritime chaparral (e.g., lower Santa Ynez River Valley, Pismo Bay, Morro Bay, and Monterey Bay [Keeley 2002b]). Greenlee and Langenheim (1990) estimated prehistoric fire return intervals near Monterey Bay to be on the order of 10 to 100 years (Table 14.3). Today, human-caused ignitions are frequent in maritime chaparral but wildfires are quickly suppressed or extinguished at roads and fuel breaks. As a result, fires now rarely exceed 100 ha (247 ac) (Davis et al. 1988a, Van Dyke and Holl 2001, Odion and Tyler 2002). In maritime chaparral to the east of Vandenberg Air Fore Base near Lompoc, Davis et al. (1989) documented only 27 fires larger than 1 ha between 1938 and 1986 that occurred in 10% to 15% of the maritime chaparral area under investigation.

As in other chaparral communities, many maritime chaparral species are dependent on or promoted by fire (Table 14.2; see Keeley, this volume). Regeneration after fire includes sprouting and recruitment from buried seeds (Fig. 14.7). Exogenous seed sources usually do not play an important role in succession (Davis et al. 1989, Odion and Davis 2000). Chronosequence studies suggest that succession after fire is largely a function of floristic composition prior to burning, differential seedling survivorship and differential adult longevity of species. Vegetation in the first several years after fire is a diverse combination of annuals and short-lived perennials recruited from the seed bank and resprouting geophytes and woody plants (Davis 1988a). Unlike other chaparral communities, the flush of post-fire annuals appears to be mainly related to removal of the shrub canopy rather than fire-induced germination of refractory seed (Tyler 1996). Herb layer biomass and diversity drop rapidly with closure of the shrub canopy 5 to 10 years after burning. After 20 to 40 years, the shorter-lived shrubs, notably the obligate-seeding California-lilac species, senesce and the community is increasingly dominated by long-lived chamise, manzanitas, and coast live oak.

Shrub dieback during the fire-free period can leave conspicuous gaps in the chaparral canopy where some herbaceous species can grow and augment the soil seed bank. These gaps experience less extreme soil heating and associated seed mortality during the next fire, and thus become microsites of higher seedling recruitment for both herbaceous and woody species (Davis et al. 1989, Odion and Davis 2000). Mortality of buried seeds during fire can reduce the

FIGURE 14.7. Maritime chaparral (being sampled by Dennis Odion and Diana Hickson) on Burton Mesa, northern Santa Barbara, two years after burning. Peak rush-rose is a conspicuous member of the diverse post-fire community.

density of viable seed of some species by an order of magnitude or more, so local variations in fuel loading and fire behavior have important consequences for post-fire vegetation composition and pattern (Odion and Davis 2000, Odion and Tyler 2002).

Maritime chaparral is more extensively invaded by exotic plant species than most other chaparral types, perhaps because it is more densely roaded and closer to human developments, and thus more prone to human disturbance and sources of exotic propagules. One alien succulent species, fig-marigold, can be widespread in maritime chaparral and establishes most successfully after fire (D'Antonio et al. 1993). Other invasive exotics include pampas grass *(Cortaderia jubata)*, perennial veldt grass *(Erharta calcina)*, and French broom *(Genista monspessulana)* (Griffin 1978b, Davis et al. 1988b, Zedler and Scheid 1988, Lambrinos 2000, Odion and Tyler 2002).

Several observers of maritime chaparral argue that, in the absence of fire, the chaparral would eventually be replaced by coastal oak or pine forests (Cooper 1922, McBride and Stone 1976, Griffin 1978b). Davis et al. (1989) reported a significant positive correlation between oak canopy cover and time since burning but noted that the increase in oaks varied widely depending on distance from the coast, soil characteristics, and fire severity. In the coastal sand hills of northern Monterey County, Van Dyke and Holl (2001) found that in the long absence of fire, remnants of Prunedale maritime chaparral had undergone significant changes in species composition and stand structure. Fire-dependent shrubs like sand-scrub ceanothus (*Ceanothus dentatus*), blue blossom, and goldenbush (*Ericmeria ericoides*) present in stands sampled from 1975 to 1976 (Griffin 1978b) were absent in a resurvey in 2000. By 2000, Pajaro manzanita and coast live oak had increased in cover from 86% to 99% and dominated the overstory. Van Dyke and Holl (2001) posited that in the continued absence of fire, coast live oak would gradually replace the long-lived obligate-seeder Pajaro manzanita, eventually converting maritime chaparral to coast live oak woodland.

## Knobcone Pine

### FIRE ECOLOGY

Knobcone pine is a medium-sized, relatively short-lived conifer that frequently grows in dense stands. Because trees self-prune poorly, they are easily killed in chaparral crown fires and depend on fire for regeneration (Table 14.2).

Despite its widespread distribution in California, there are remarkably few post-fire studies of knobcone pine. Keeley et al. (1999) studied the regeneration of this species in the central Santa Lucia Mountains after a fire in 1994. Populations of serotinous species are particularly vulnerable to extinction if they reburn before a cone bank develops that is sufficient in size to replace the population after the next fire—what Zedler (1995) terms "immaturity risk" (as discussed in Chapter 6). They examined the regeneration of knobcone stands that reburned after a fire just eight years earlier. Seedling recruitment following the 1985 fire was abundant, and because knobcone pine produces cones at an early age (two years), a partial aerial seed bank had developed by the second fire. Seedling recruitment after the second fire was low (1–2 seedlings/$m^2$) and patchily distributed compared to recruitment after the 1985 fire. Nevertheless, local extinction appeared to be averted by the presence of a relatively low number of new cones.

The impact of two fires just eight years apart likely would have been very different for Coulter pine, another serotinous species growing in the same area. Because Coulter pine does not produce cones until about ten years of age, few, if any, seedlings would have appeared after the second fire.

TABLE 14.5

Fire regime characteristics of lower montane zone and upland forests

| Vegetation type | Knobcone pine | Sargent cypress | Coulter pine |
|---|---|---|---|
| Temporal | | | |
| Seasonality | Spring/summer–fall | Spring/summer–fall | Summer–fall |
| Fire-return interval | Medium–long | Medium truncated–long | Short–medium |
| Spatial | | | |
| Size | Large | Large | Medium–large |
| Complexity | Low | Low–moderate | Low–moderate |
| Magnitude | | | |
| Intensity | High | High | Multiple |
| Severity | High | Moderate–high | Multiple |
| Fire type | Crown | Crown | Multiple |

#### FIRE REGIME–PLANT COMMUNITY INTERACTIONS

Knobcone pine, like Coulter pine and Sargent cypress, often grows in close association with highly flammable vegetation like chaparral. As a result, knobcone pine stands regularly burn in stand-replacing fires at frequencies matching the surrounding vegetation (Table 14.5).

### Sargent Cypress

Within the region, Sargent cypress forms an archipelago of small stands that extend from the northern Santa Lucia Range to the southern part of the bioregion above San Luis Obispo. It is almost entirely confined to serpentine outcrops where other rare plant taxa are associated with it (Hardham 1962). Three of these island-like forests are formally designated botanical areas on Los Padres National Forest.

#### FIRE ECOLOGY

Among the four cypress species in the region, Sargent cypress is the only species that has been studied after fire (Table 14.2). Sargent cypress is a fire-dependent, obligate-seeding species that releases prodigious numbers of small, wingless seeds after crown fires.

#### FIRE REGIME–PLANT COMMUNITY INTERACTIONS

After a wildfire swept the Cuesta Ridge Botanical Area in 1994, Ne'eman et al. (1999) reconstructed pre-fire stand characteristics (adult density, cone and seed densities, age, etc.) using the skeletal remains of trees in even-aged stands that ranged from 20 to 95 years. The number of cones per tree increased rapidly after 80 years as tree densities thinned from $0.8/m^2$ in young-aged stands to $0.4/m^2$ in the oldest ones.

Seedling densities ranged from $6.3/m^2$ to $81.7/m^2$ but seedling density was negatively correlated with tree density. The highest seedling densities occurred in stands younger than 60 years rather than in the oldest stands with the highest number of cones per tree. They attributed low seedling densities in the oldest stands to either reduced seed viability with age or to higher-intensity fires in older stands (Table 14.5). Indeed, for some cypress species, seed viability decreases rapidly with age (De Magistris et al. 2001). They concluded that fires burning at intervals as short as 20 years posed little risk (i.e., immaturity risk) to the regeneration of the species at this site, presumably because 20-year-old stands had an adequate cone bank. Nevertheless, the fire that burned these Sargent cypress forests also reburned the knobcone pine forests described above (Keeley et al. 1999) just a few kilometers away. Had the Sargent cypress stands burned after eight years, as some of the knobcone pine forests did, much of the cypress forest may have been lost.

### Coulter Pine

Coulter pine is the most widely distributed closed-cone species in the Central Coastal bioregion. Its range is more or less linear and extends from northern Diablo Range in Contra Costa County along the coastal Santa Lucia Range to Figueroa Mountain. Inland populations are rare and more scattered and trail down the Diablo Range (Ledig 2000).

#### FIRE ECOLOGY

In the southern Coast Ranges, Coulter pine exhibits considerable cone-habit variation that appears to be directly related to fire regime (Borchert 1985). Over much of its range, Coulter pine grows as an overstory tree in a matrix of dense montane chaparral (Borchert et al. 2004). In this setting, crown fires are inevitable because fire carries easily from the shrub layer into the crowns of the pines that self-prune poorly (Table 14.2). Typically, large tracts of pines

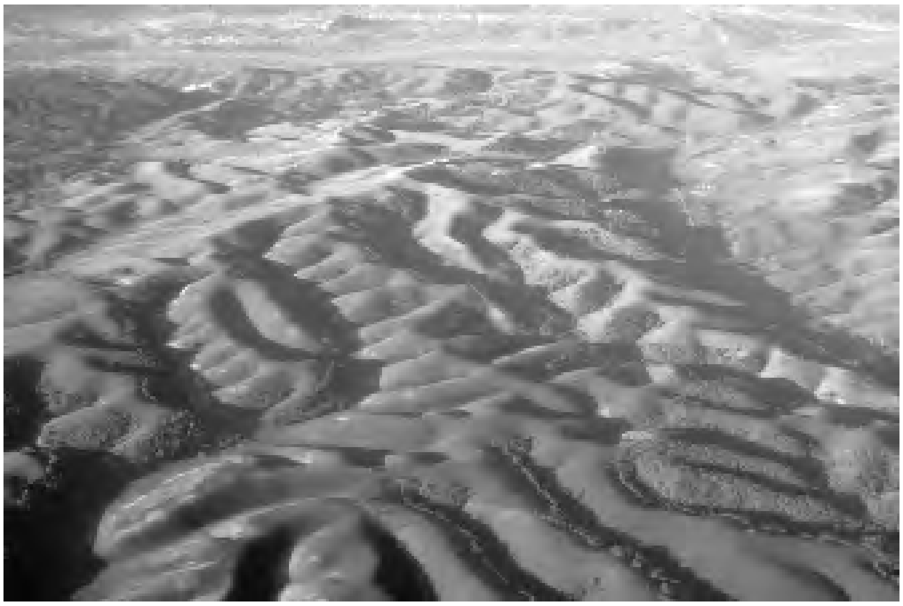


FIGURE 14.8. Aerial view of annual grassland and oak forest topo-mosaics of the Interior Coast Ranges, northeast of Salinas in San Benito County.

succumb. Nevertheless, in some topographic positions (drainages and ridgetops), small stands survive (Borchert 1985, Borchert et al. 2003) where fire intensity is diminished. Despite its relatively thick bark, moderate-intensity fires easily kill Coulter pine (Borchert et al. 2002). Stand-killing fires, however, are not just confined to chaparral. Stands with an understory of dense Sargent cypress or canyon live oak in steep topography often suffer complete mortality.

In an environment of repeated stand-replacing fires, Coulter pine tends to be highly serotinous. Heat from both the burning chaparral and the porous canopy of long needles breaks the resinous seal of the cones and seeds fall *en masse* into the ash bed. Although winged, the heavy seeds do not disperse far from the tree except perhaps in strong winds (Borchert et al. 2003, Johnson et al. 2003). Once on the ground, rodents and birds quickly harvest seeds and bury them in caches of 1 to 15 seeds per cache. In fact, most seedlings emerge from unrecovered caches. Seedlings are drought tolerant and seedling mortality is relatively low, especially when compared to early seedling mortality of other serotinous pines (Borchert et al. 2003).

At about age 10, saplings begin to produce cones but because the cones are heavy, they require the support of the tree bole and only appear on the ends of branches after the limbs are sufficiently stout. A small percentage of cones remain closed and securely attached to the tree for decades. As the tree grows, cones accumulate creating an aerial seed bank. Some cones open or are predated by western gray squirrels *(Sciurus griseus)* or white-headed woodpeckers *(Picoides albolarvatus)* (Koch et al. 1970), but seeds that remain encased in the closed cones receive a high degree of protection as evidenced by a seed viability of 95% in 25-year-old cones (Borchert 1985).

#### FIRE REGIME–PLANT COMMUNITY INTERACTIONS

Coulter pine is not confined to chaparral in its distribution. On the Central Coast, it frequently associates with coast live oak (Campbell 1980, Borchert et al. 2002), and occasionally with valley oak or other hardwoods in both woodlands and forests. In these forests, Coulter pine is not serotinous, or is only moderately so. Where sites are productive and trees grow large, the continuous shrub understory is absent or poorly developed. Thus, surface fires are more common than crown fires and adult Coulter pine mortality is low (Table 14.5). Seedlings establish after fires from cones of the current year or they establish and grow to a fire-tolerant size in the interval between fires (Borchert 1985).

### Interior Coast Ranges Subregion

Ecological zonation has been obscured by extensive type conversion of shrublands to grassland, but it is still possible to discriminate two general ecological zones: a lower-elevation grassland zone and a higher-elevation blue oak woodland-chaparral zone. Ten percent of the subregion has been converted to urban and cropland uses.

The interior valleys and foothills are dominated by alliances such as California annual grassland and California buckwheat (Fig. 14.8). Remnant valley oak woodlands are present in larger stream valleys on deeper loamy soils across the region.

Mid to high elevations support blue oak woodlands, chamise chaparral, and other chaparral alliances such as buck brush and Eastwood's manzanita *(Arctostaphylos glandulosa)*, blue oak *(Quercus douglasii)*, and blue oak–gray pine. The latter two alliances are especially widespread in the Diablo Range. The only montane forests in the inland region are the unusually open stands of Jeffrey pine *(Pinus jeffreyi)*, incensecedar (*Calocedrus decurrens*), and Coulter pine that occupy the serpentine areas of San Benito Mountain.

### Overview of Historic Fire Occurrence

#### PREHISTORIC AND HISTORIC PERIODS

There is little doubt that Native Americans augmented vegetation burning in the Interior Ranges just as they did along the coast. Greenlee and Moldenke (1982) assert that the Castanoans were burning grasslands and oak woodlands annually or semi-annually. Chaparral and foothill pine woodland were likely thinned or reduced in extent by the high frequency of deliberate or inadvertent fires in the region (Keeley 2002b).

Aboriginal burning declined with the advent of the Mission Period in the last quarter of the eighteenth century (Greenlee and Langenheim 1990). By the time Mexico ceded California to the United States in 1850, regular burning of oak woodlands by Native Americans had ceased but chaparral burning probably expanded both to increase rangeland area and to facilitate travel. Fires still occurred but they were more likely to be accidental or lightning-caused rather than deliberate. For example, newspaper accounts during the period 1855 to 1920 recorded roughly 60 wildfires in San Benito County; around the same number were reported in Monterey County (Greenlee and Moldenke 1982). Nearly all of these fires occurred between July and October.

#### CURRENT PERIOD

Maps of fires that have burned since 1950 have been compiled by the Forest Service and California Department of Forestry and Fire Protection (CDF&FP) (Map 14.6, http://frap.cdf.ca.gov/projects/fire_data/fire_perimeters/index.asp). Only fires larger than 120 ha (300 ac) are mapped on private lands. We also obtained fire history records from Pinnacles National Monument, which provide a more complete and accurate history of fires from the interior Diablo and Gabilan Ranges. In comparing the two datasets we found the CDF&FP data to be incomplete for lands outside of the National Forests. Nevertheless, the CDF&FP data provide a good general picture of fire frequency and size across the region. Based on these records, at least 40% of the region has burned at least once since 1950, with fires concentrated in shrublands and mixed evergreen forests of the northern Santa Lucia Ranges.

Although uncommon, lightning fires occur with greater frequency in the Interior Ranges than in the Santa Lucia Ranges or Santa Cruz Mountains. Between 1930 and 1979, fire history data record 142 lightning-caused fires out of a total of 3,086 fires (4.6%) in the Gabilan and Diablo Ranges (Greenlee and Moldenke 1982). Eighty-six percent of these lightning fires occurred in grasslands or oak woodlands and, with one exception, all lightning fires started between May and October. Nearly half of the fires burned in September.

Humans started 95% of all recorded fires from 1930 to 1979 (Greenlee and Moldenke 1982). Some of this is due to the widespread use of controlled burning for rangeland improvement in the region. Sixteen percent of the fires recorded during this period were characterized as deliberate “brush burning,” and over the period 1951 to 1978, 22,814 ha (56,350 ac) were deliberately burned in San Benito and western Fresno Counties alone. Although grass and blue oak woodland cover over 50% of the Gabilan and Diablo Ranges, and despite the relatively high frequency of lightning ignitions in those vegetation types, roughly 55% of the area that burned between 1930 and 1979 was classified as “brush,” and less than 30% as grassland or woodland (Greenlee and Moldenke 1980).

At least 15% of the Interior Ranges burned at least once between 1950 and 1998 in fires larger than 120 ha (296 ac) (Map 14.6), compared to 40% of the Santa Lucia Ranges and 3% of the Santa Cruz Mountains. Large fires in the Interior Ranges are most common in southern San Benito County (Hepsedam Peak and San Benito Mountain) and in the Gabilan Ranges north and east of Pinnacles National Monument. Based on fire scar data and maps of fire perimeters, Greenlee and Moldenke (1982) concluded that fire suppression efforts have reduced fire frequency in the region from every 10 to 30 years prior to 1930 to a current recurrence interval of 25 to 35 years, depending on vegetation, topography, and exposure.

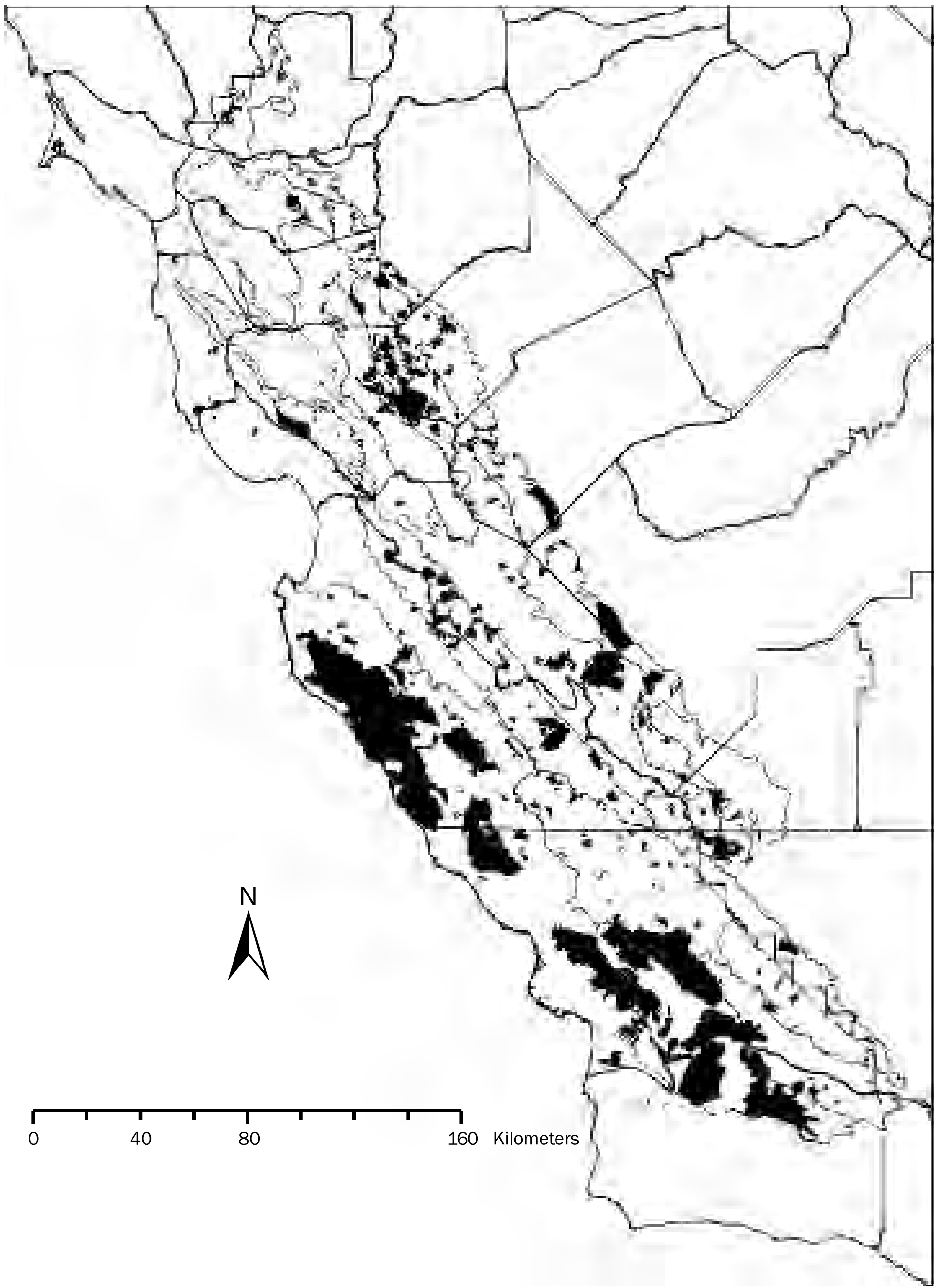
In a more recent analysis, Keeley (2004) analyzed CDF&FP fire history data for three counties east of San Francisco Bay (Santa Clara, Alameda, and Contra Costa Counties) and reported a sharp rise in the number of fires after 1950 and then a leveling off after 1990 in the East Bay region. Fire frequency was highly correlated with regional population growth until recent years. Area burned showed little directional change over the same period, although moderate to large fires have become less frequent and small fires more frequent over the period of record. Based on these trends in twentieth-century burning patterns, Keeley (2004) concludes that fire suppression cannot account for the widely observed colonization of grasslands by shrubs and trees and that cessation of grazing is a more likely explanation.

### Major Ecological Zones

The fire ecology and fire regimes in widespread and characteristic vegetation types in this zone such as blue oak woodland, annual grassland, and chaparral are covered in other chapters in this volume (see chapters by Wills and Keeley). Systematic comparisons of the fire ecology of these types in the Interior Coast Ranges versus other parts of their distributions are not possible at this time.

## Subregional Differences in Modern Fire Regime

Although existing fire history data are too incomplete and too inconsistent to allow detailed quantitative comparisons of the Santa Cruz, Santa Lucia, and Interior Ranges, they do suggest several striking interregional differences in modern




MAP 14.6. Locations of areas burned at least once since 1950 in fires greater than 120 ha (300 ac) in size (black areas), superimposed on the fire regions displayed in Map 14.5. Fire perimeter data were provided by the California Department of Forestry and Fire Protection.

fire regimes that appear related to vegetation, climate, and ease of suppression.

Fire suppression has dramatically altered the fire regime of the Santa Cruz Mountains. Although the terrain is fairly rugged, the mountains are densely roaded and much more accessible to suppression forces than are the Santa Lucia Ranges. Furthermore, many fires in this area begin as understory burns in coast redwood–Douglas-fir forests. Under the more moderate fire weather conditions and higher fuel moistures typical of this area, fires are more readily contained than shrubland fires to the south. This situation may be changing as the forests accumulate more understory ladder fuels (Greenlee 1983).

In contrast to the Santa Cruz Mountains, the Santa Lucia Ranges are characterized by large wildfires occurring mainly in rugged terrain dominated by crown fire–prone shrublands and mixed evergreen forests. Fires are somewhat larger in the chaparral-dominated southern Santa Lucia Ranges of Santa

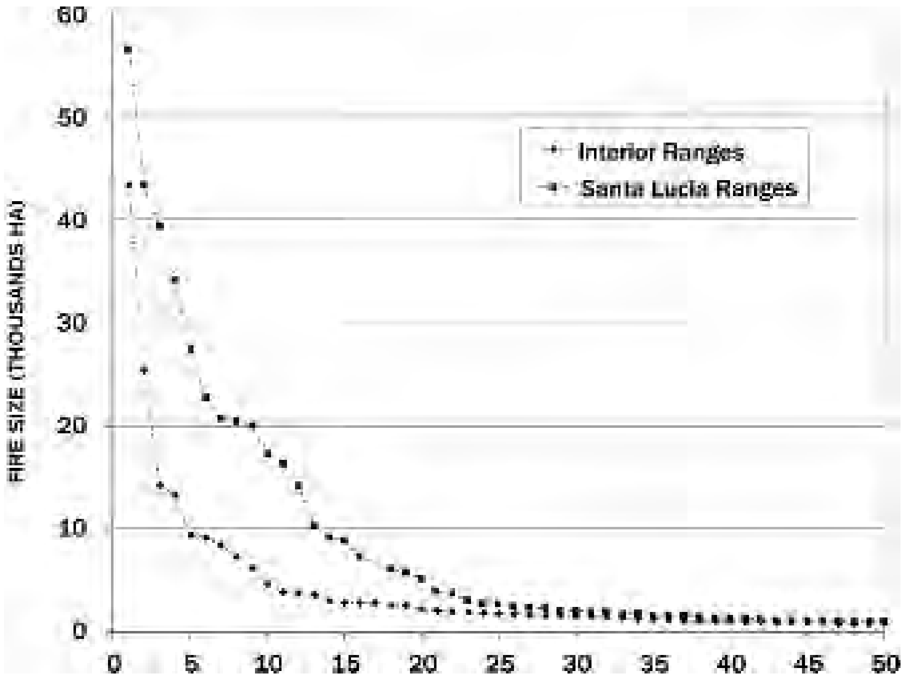



FIGURE 14.9. Rank order of fires vs. burn patch size for the 50 largest fires recorded in the Interior Ranges versus the Santa Lucia Ranges (Regions 3 vs. 4 in Map 14.5) for the period 1950–1997. Mapped fire boundaries for fires larger than 120 ha (300 ac) were analyzed.

Barbara and San Luis Obispo Counties than in the northern Santa Lucia Ranges of Monterey County. Areas experiencing large wildfires occur mainly within Los Padres National Forest where a sparse road network limits access for fire suppression. In the south coastal and interior Santa Lucia Ranges, large fires are promoted by winter and spring drought, heat waves during the fire season, and high winds associated with Santa Ana conditions. However, high winds are not a prerequisite for large wildfires, as evidenced by numerous large burns in the northern Santa Lucia Ranges. It appears that a combination of ample fuel, low summer fuel moisture, high temperatures and low humidity, and steep terrain more than meet the requirements for infrequent, large wildfires. Although modern fire suppression has greatly reduced wildfires near the coast and in the foothills, it appears to have had much less effect on the frequency of large wildfires in the montane zone.

The modern fire regime of the Interior Ranges is more similar to that of the Santa Lucia Ranges than the Santa Cruz Mountains but there are some notable differences: In the Interior Ranges lightning fires are more frequent, more fires are set deliberately for range improvement, and fires do not attain the size of the largest fires in the Santa Lucia Ranges. Although the CFD&FP fire perimeter maps show more fires larger than 120 ha (296 ac) in the Interior Ranges than in the Santa Lucia Ranges for the period 1950 to 1998 (293 vs.189 ha [724 vs. 467 ac]), very large fires are much more likely in the Santa Lucia Ranges and the total area burned is also much greater (Fig. 14.9).

## Management Issues

Sound vegetation management using fire depends fundamentally on a good understanding of the fire ecology of the species or plant communities in question. Thus, it is somewhat surprising that the Central California Coast, which has one of the richest arrays of plant communities in the state, has so few fire ecology studies, especially considering the major vegetation types that cover much of the bioregion. For example, four associations of coastal sage scrub are represented and although Venturan, Lucian, Diablan, and Franciscan cover more than 2,500 $km^2$ (925 $m^2$) of the region (Davis et al. 1998) we know of only one fire ecology study in Franciscan coastal sage scrub by Ford (1991). Similarly, chaparral makes up 20% (7,765 $km^2$, 2,998 $m^2$) of the region but there are only two postburn studies of prescribed fires in nonmaritime chaparral, one in Pinnacles National Monument (Florence 1985) and the other in the Mount Hamilton Range (Dunne et al. 1991). By comparison, the number of fire ecology studies of chaparral in the South Coast bioregion number more than 100. Finally, this region is one of the major repositories of mixed evergreen forests (1,625 $km^2$) in the state but, except for limited post–Marble Cone fire observations by Griffin (1978c), there are no formal fire ecology studies in this highly variable type.

In sharp contrast to many of the common alliances in the bioregion, rare alliances have received considerably more research attention. This is perhaps not surprising since a number of these types, such as maritime chaparral and Monterey pine forests, are at risk from urbanization and other land conversions (Cylinder 1997, Hillyard 1997, Lambrinos 2000). Other rare types like the narrow endemic Santa Lucia fir (*Abies bracteata*) (Talley 1974) and sugar pine forests in the northern Santa Lucia Mountains are better protected on national forest lands and yet these alliances have not been immune from management activities, like post-fire grass seeding for erosion control, that have threaten their persistence on the landscape (Griffin 1982).

In this chapter we have highlighted some similarities but also some major differences in fire regimes among the geographic subregions and major vegetation types of the Central California Coast bioregion. This heterogeneity and the pressing need for more ecological research notwithstanding, we would be remiss if we did not reiterate four important management issues that face fire and natural resource managers in the Central Coast bioregion, notably: climate change, fire and exotic species, management of fire-dependent species, and fire management at the wildland-urban interface.

#### Climate Change

Analyses of historical climate data as well as models of predicted future climates under elevated carbon dioxide make it abundantly clear that the recent past that has formed the basis for the design of fire policy and management may not serve as the guide to the future fire regimes and their management in the region. Fire incidence and total area burned depend on the frequency of extreme weather events, longer-term variation in rainfall and drought severity, and associated changes in vegetation productivity and composition (Davis and Michaelsen 1995). The region is warming (Cayan et al. 2001) and the magnitude of interannual variability in climate appears to be increasing (although there is less certainty about the latter) (Haston and Michaelsen 1997). Depending on trends in winter and spring precipitation, we speculate that climate change could well increase the likelihood of wildfires in some vegetation types, notably the coast redwood–Douglas-fir forests of the Santa Cruz Mountains and the mixed evergreen forests of the northern Santa Lucia Ranges.

#### Fire and Non-Native Species

Coastal and foothill vegetation types of the region are now extensively invaded by non-native plant species and this trend is likely to continue, especially given rapid human population increase and development in some parts of the region. Deliberate use of fire to convert shrublands and closed woodlands to grasslands has promoted invasion of non-native plants into many areas (Keeley 2001). In the past, the spread of some exotics into shrublands was undoubtedly promoted by post-fire seeding, but this practice appears to have become far less prevalent in recent years. Now there is increasing interest by managers in using fire to control non-native plant species, despite the mixed success of efforts to date and the need for better understanding of the fire ecology of target species and communities, especially in response to repeated burning (D'Antonio 1993, Keeley 2001, Alexander and D'Antonio 2003).

Recent widespread mortality of tanoak, black oak *(Quercus kelloggii)*, and coast live oak at the northern end of the bioregion has been linked to the exotic pathogen *Phytophthora ramorum* or Sudden Oak Death Syndrome (SODS) (Rizzo et al. 2002). The disease now extends over at least 300 km (186 mi) of the Central Coast bioregion. In heavily infested areas of Marin County, mortality of tanoak and coast live oak has been as high as 18% to 50% and 15% to 20%, respectively (Kelly and Meentemeyer 2002, Spencer and O'Hara 2003). The effects of increased dead fuel loading, canopy opening, and associated changes in understory composition and fuel moisture on fire regime and post-fire succession could be profound. Studies are underway to better understand fire behavior in SODS-affected areas. However, we would re-emphasize the need for systematic research on the fire ecology of both mixed evergreen forests and coast live oak forests in both SODS-free and SODS-affected areas to better understand the management implications of this pathogen in the region.

#### Management of Fire-Dependent Species

As noted in the sections on maritime chaparral and closed-cone conifers, there are many rare and endemic species in the region whose distribution and abundance is closely tied to fire regime. Fire management for many of these species has become increasingly difficult due to their close proximity to residential areas. In some areas, managers have resorted to mechanically clearing fuel breaks, setting prescribed burns in relatively cool and damp spring or early winter conditions, or shortening the time between burns to prevent excessive fuel build-up. Such management can have unintended negative impacts on native species and communities. Mechanical clearing can promote non-native species and native vegetation may be slow to recover (Stylinski and Allen 1999). Burning outside the normal fire season and high-frequency burning favors some species, like sprouters, but can operate strongly against obligate-seeding species, and the benefits for public health and safety are often unclear (Keeley 2002a).

#### Wildland-Urban Interface

In 1991, the deadly Tunnel fire killed 25 people and destroyed 3,810 dwellings in the Oakland Hills. A combination of drought-dry vegetation, high temperatures, low humidity, steep topography, and Santa Ana-strength winds that forced the fire down slope created a firestorm that defied control for several days (Ewell 1995). Although many of the cities in the bioregion are located in agricultural areas (e.g., the developed plains, valleys and terraces ecological zone) and are immune from wildland fires, others, like San Luis Obispo (which has been threatened twice in the last 25 years by chaparral fires), are vulnerable to fires burning from wildland areas. The historically unprecedented Tunnel fire provides a vivid worst-case example of fire management problems that other areas in the bioregion will face as California's population continues to grow exponentially and the populace pushes into and up against flammable wildlands.

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GEOLOGY—Foundation of the present; key to California's future.

# CALIFORNIA GEOLOGY

December 1977

35¢

## MARBLE CONE FIRE
## ......EFFECT ON EROSION

# MARBLE CONE FIRE

# ......EFFECT ON EROSION

By

GEORGE B. CLEVELAND, Geologist
California Division of Mines and Geology

The Marble Cone fire of August 1977 is the third largest fire in California history. It consumed vegetation in a large part of the Ventana Wilderness area, destroying valuable watershed in four major drainage basins in the northernmost part of the Santa Lucia Mountains, Monterey County, California (see map; front cover; photos 1–3).

The data in this survey of erosion conditions within the Big Sur drainage basin were rapidly assembled and interpreted because of the serious hazards that may develop during this winter. The area was examined briefly on the ground, but the analysis is based mainly on air photographic interpretation of geologic features, vegetation, and geomorphology. I am indebted to the personnel of the U.S. Forest Service for valuable discussion of the erosion problems and for the loan of air photographs and unpublished maps.

## PHYSICAL SETTING

The Big Sur drainage basin covers an area of about 38,000 acres, with about 30,000 acres situated in the upper basin. About 28,000 acres in the upper basin were burned over during the fire (see map).

### Geology

The details of the geology and mineral resources of the area have been reported on by Pearson and others (1967). The basin is underlain mainly by strong crystalline rocks which reflect their resistance to erosion by forming steep slopes. Below the steep slopes, highly irregular drainage courses have developed.

The Sur Series, a sequence of metamorphic rocks, is the principal rock unit in the basin. A soil mantle supporting sparse to heavy vegetation has developed on these rocks. The vegetation on the upper slopes is composed mainly of hardwoods and dense chaparral. Conifers, including some redwoods, are primarily found along the drainage courses. The extensive root mat of the plant cover tends to hold the slopes in place by protecting the ground from direct impact of precipitation and reducing ground moisture through evapo–transpiration. Locally, landslides in areas underlain by the metamorphic rocks occur along the principal drainage courses where the slopes have been undercut by stream erosion.

Granitic rocks occur mainly in two large masses in the eastern part of the basin and locally elsewhere. These rocks regularly shed their weathered products and only relatively thin rocky soils cover the slopes. These rocky soils are thinly covered by vegetation.

Minor bodies of sedimentary rocks occur in the southwest part of the area. These rocks are primarily sandstones and conglomerates and are generally covered by relatively dense vegetation.

### Rainfall Patterns

The Big Sur region lies in a climatic zone of high annual rainfall and short duration high–intensity rainfall. The annual rainfall over the basin averages from 50 to 60 inches, but reaches 100 inches along the coast ridge. At Cold Spring Camp (elevation 1,350 feet) during the period July 1940 to June 1941, 161 inches of rain fell — the greatest recorded in California (Pearson and others, 1967). During the winter of 1972–1973 high–intensity rainfalls caused floods, debris flows, and mudflows. At Cold Spring Camp, 0.86 of an inch of rain fell in 18 minutes (U. S. Forest Service). Within 15 minutes, 0.44 of an inch of rain was recorded at an elevation of 216 feet on the lower Big Sur River (Cleveland, 1973). A review of projected rainfall intensities over the Big Sur basin indicates a pattern of precipitation that increases steadily from the coastline up to the southwestern edge of the basin, then rises abruptly to a maximum in the northeastern part of the basin (Miller and others, 1973).

Photo 1. Big Sur River Gorge. Runoff and debris from about 28,000 acres in the upper Big Sur drainage basin, burned over during the Marble Cone fire, must pass through this narrow defile.

# L E G

## GEOLOGIC UNITS[1]

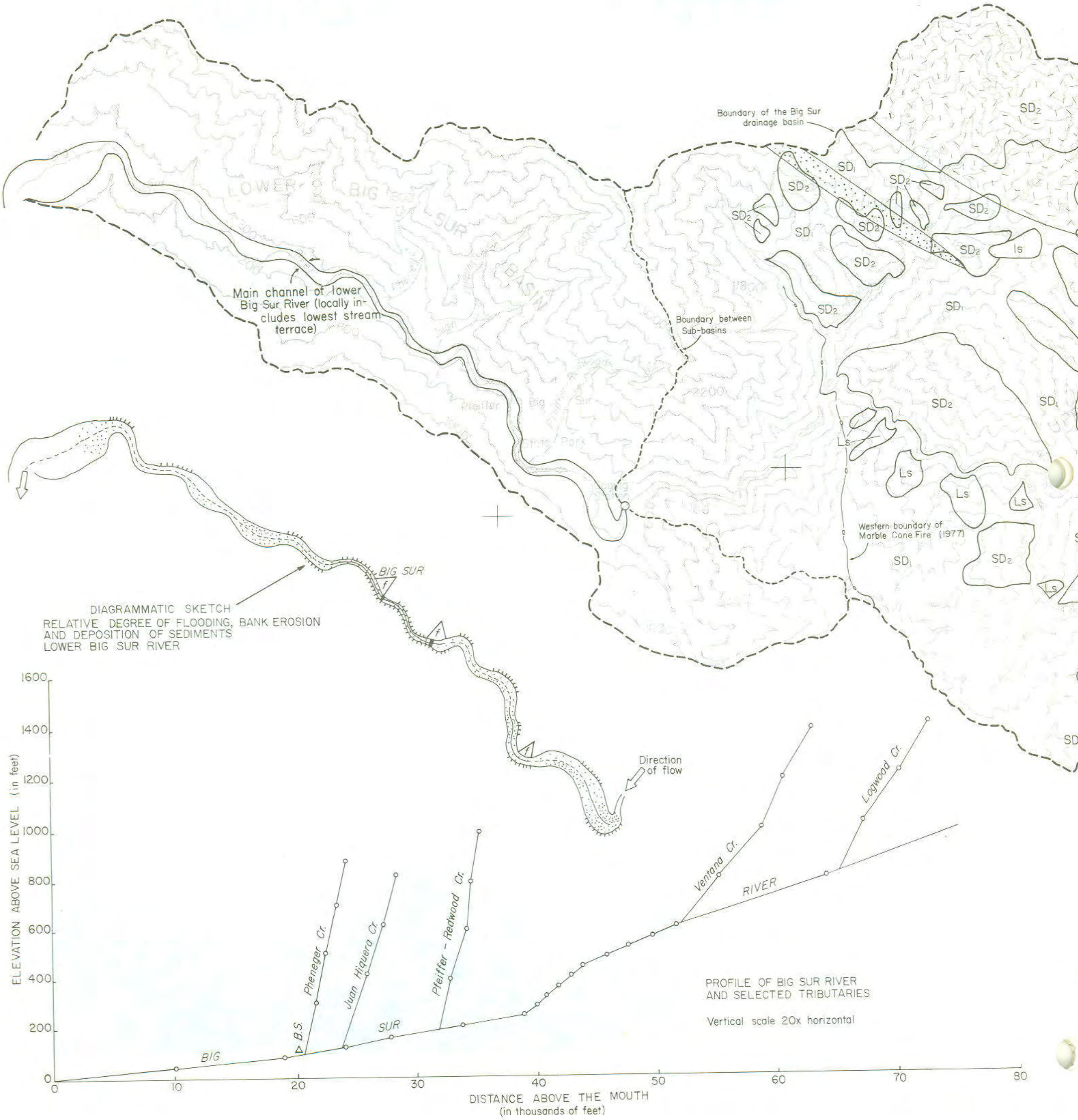
### SURFICIAL ROCKS

**SLOPE DEPOSITS**
Soil and weathered bedrock

| | |
|---|---|
| $SD_1$ | *Relatively thick deposits, anchored and protected from erosion by vegetation cover* |
| $SD_2$ | *Relatively thin deposits in areas of rapid sheet erosion on relatively steep slopes with sparse cover of vegetation* |

**LANDSLIDE DEPOSITS**
Bedrock slope failures

| | |
|---|---|
| Ls | Massive rock failures<br>*Debris at surface anchored and protected from erosion by cover of vegetation* |
| ls | Massive rock failures<br>*Debris deeply eroded and sparsely covered with vegetation; locally includes debris flows* |



# E N D

BEDROCK

CRETACEOUS and TERTIARY

Sedimentary rocks
*Mainly sandstone and conglomerate*

JURASSIC (?) and CRETACEOUS (?)

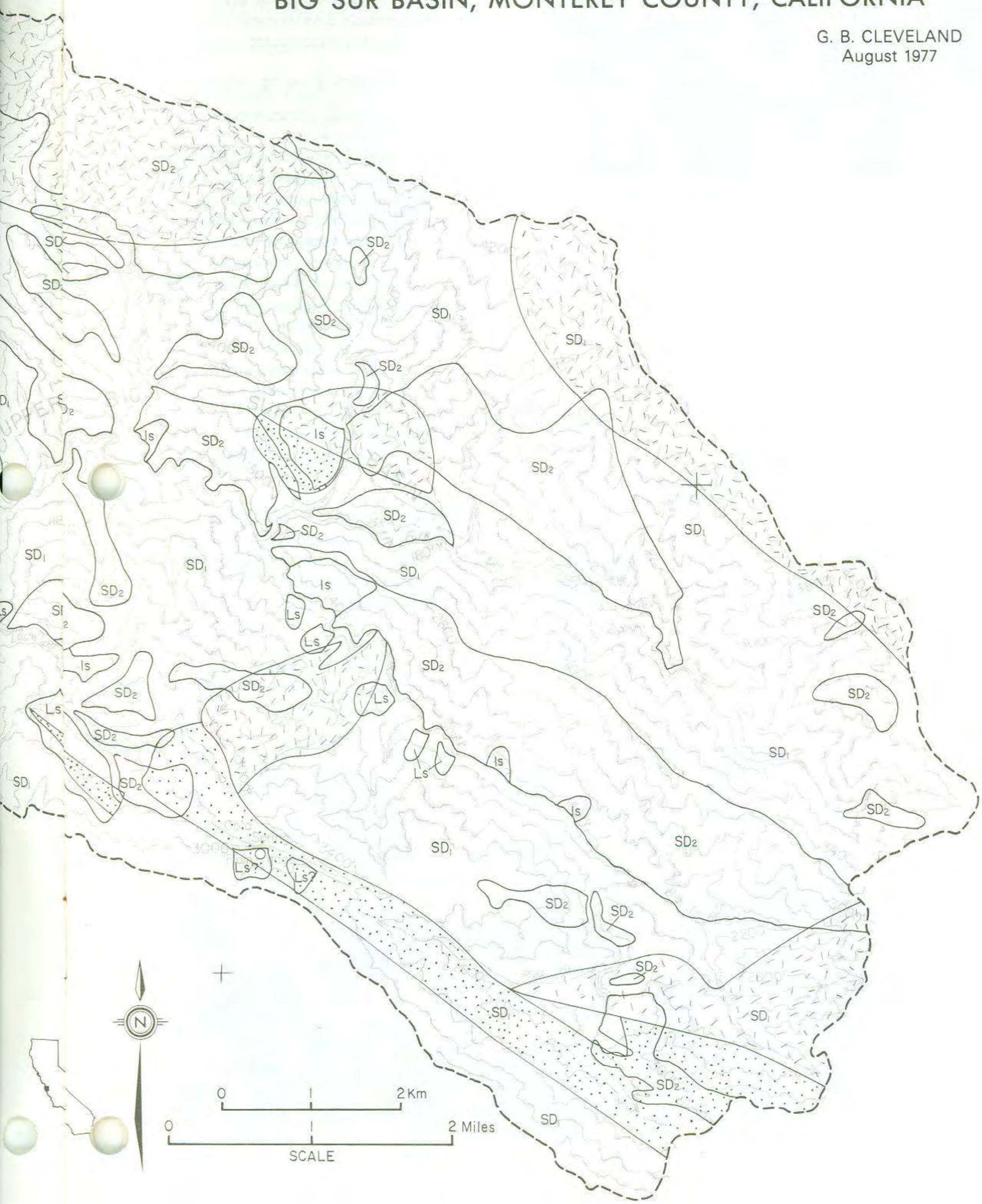
Intrusive rocks
*Mainly quartz diorite and granodiorite*

PRE-CRETACEOUS

Metamorphic rocks
*Mainly gneiss and schist of the Sur Series*

## EROSION PROPENSITY FOLLOWING MARBLE CONE FIRE, BIG SUR BASIN, MONTEREY COUNTY, CALIFORNIA

G. B. CLEVELAND
August 1977




## GEOLOGIC PROCESSES AND PRODUCTS[2]

UPPER BIG SUR BASIN

AREAL EROSION

SD₁

*Areas where loss of vegetation will relea significant amounts of slope debris to Big S River system; probably, in part, in the form mudslides and debris flows.*

SD₂ ls

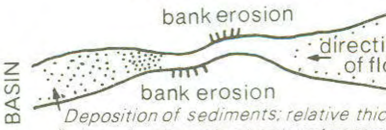
*Areas where loss of vegetation will relea moderate amounts of slope debris to Big S River system*

Ls

*Bedrock landslides where loss of vegetati will lead to accelerated erosion of near–s face materials and possible reactivation large landslide masses due to undercutting slopes by channel erosion*

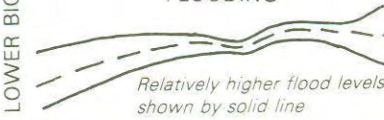
LOWER BIG SUR BASIN

CHANNEL EROSION AND SEDIMENTATION[3]



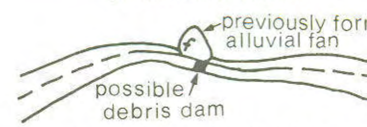

*Deposition of sediments; relative thic of deposits shown by density of pattern*

FLOODING[4]



*Relatively higher flood levels shown by solid line*

DEBRIS BLOCKAGE OR RESTRICTI OF STREAM FLOW[5]




Partial restriction or damming of stream by landslide debris, fanglomerate or by c nel debris (rock and vegetation) stalled jammed by riparian vegetation

## NOTES

1. Shown only in area of Marble Cone (1977); bedrock units shown beneath ficial units; bedrock units modified f Pearson and others (1967).
2. Effects of normal or above–nor precipitation on terrain due to loss vegetation following Marble Cone fire fluence of fire will diminish as vegeta recovers, probably within a few years
3. Channel erosion will be minimal wh strong bedrock comprises river ba zones of deposition shown are eph eral, sediments subject to transporta and redeposition downstream depend on nature of runoff.
4. Flood levels determined by channel ume (cross section) – local restriction the channel such as crowding of stream by alluvial fan development f tributary drainages and by stream flov on top of previously deposited rock bris.
5. Location and number of possible c along channel (speculative).

Photo 2. Burned over area along Logwood Creek in upper Big Sur drainage basin; view east from Coast Ridge Road.

## EROSION

### Upper Big Sur Basin

The upper Big Sur basin has been divided into areas of relative erosion propensity based on susceptibility to sheet erosion and landsliding prior to the Marble Cone fire. Air photographic examination, of photographs taken in 1968, indicated that certain areas were undergoing relatively more rapid erosion than other areas. These areas ($SD_2$ on the map) are generally in steep terrain, unprotected by an adeqaute cover of stabilizing vegetation, and are not prone to landsliding except locally where debris flows have occurred. A relatively thin layer of weathered rock and soil covers the slopes, but some stream channels below the slopes are choked with significant amounts of weathered debris. This indicates that these slopes were supplying much of the sediment load carried by the Big Sur drainage system. The cumulative extent of these areas amounts to about 40% of the upper basin and is probably the main source of the 22 acre feet of sediment produced yearly (U.S. Forest Service, 1977).

The balance of the basin ($SD_1$ on map) was characterized by relatively stable slope materials on gentle to steep terrain, anchored and protected from rainfall and runoff by a relatively dense cover of vegetation. Thick accumulations of soil and weathered rock debris cover these slopes. Bedrock landslides occur along the channels of the major drainages. These landslides, which were mantled with a dense and mature forest cover, appeared to be relatively stable under the prevailing conditions in 1968. Although part of the basin was burned over in 1924, most of the debris on the slopes has been accumulating since the last major fire–flood sequence in the upper basin. This sequence began with a fire in 1907 and was followed by floods in 1907–1908; 1908–1909; and 1909–1910 (Jackson, 1977). Therefore, in 60% of the basin a large new source of erodable debris is available to be transported in the Big Sur drainage system.

Coupled with this volume of debris will be a moderate increase in sediment yield originating from the areas of normally active erosion ($SD_2$) prior to the fire. Moreover, channel deposits have been accumulating below these slopes for more than 50 years and these materials will be an additional source of sediment.

### Lower Big Sur Basin

The last 8 miles of the Big Sur River occupies a relatively wide channel and flows down a gentle gradient to the sea. It was in this subbasin that the Molera fire and destructive debris flows occurred in 1972 (Cleveland, 1973). This reach of the river represents the conduit, through which all the water and sediment from the upper basin must pass to reach the sea. Most of the manmade development in the Big Sur area also is concentrated here.

### Relation of Molera Fire to Marble Cone Fire

The Molera fire of 1972 occurred in the lower Big Sur basin. The debris flows of 1972 occurred in the steep tributary drainages off the mountain front east of Big Sur. Much of the energy developed to mobilize the debris was dependent on the steep gradients of the channels. The gradients of Pheneger, Juan Higuera and Pfeiffer–Redwood Creek, where the debris flows occurred, are shown on the map drawn to the same scale as that of the Big Sur River. In the 5 years since the Molera fire much of the vegetation has recovered and future runoff rates would not approach those that were associated with the storms of 1972.

The Marble Cone fire burned through 94% of the vegetation cover in the upper Big Sur drainage basin and upset the equilibrium between established terrain features and the climate. The destruction of the greater part of the vegetation in the basin will prevent normal rainfall infiltration and reduce evapo–transpiration. This will lead to rapid runoff from an area of

Photo 3. Dikes around structures near mouth of lower Big Sur River. Dikes were constructed to provide protection from floodwaters.

44 square miles. If the rate of rainfall approaches some of the high values already recorded, sufficient stream energy will be created to mobilize a major part of the debris in the basin. Present conditions indicate that the volume of debris will be at least several orders of magnitude greater than normal.

## PROJECTED EFFECTS IN LOWER BIG SUR RIVER BASIN

### Debris Flows

Although major terrain features have been significantly changed by the fire, the nature of future weather conditions will establish the degree to which these changes will affect the physical environment of the lower Big Sur basin. The total rainfall and the pattern in which it is delivered will determine the amount of stream energy available for erosion at any one time. Several sets of conditions can be postulated, among these the most likely are:

(1) Normal rainfall spread out rather evenly over the rainy season would lead to above average runoff and the deposition locally of significant amounts of mainly fine–grained sediments. Bank erosion would be minimal and flooding moderate except along the narrowest reaches of the channel. Occasional high–intensity rainfall of small total amount could probably be absorbed within the upper basin. Slope debris would be transported short distances, but only moderate amounts of debris would reach the lower basin.

(2) Above average rainfall delivered in a series of widely spaced heavy storms spread over the rainy season would lead to short term rapid runoff and the transportation of large amounts of fine to coarse sediments off the slopes and into the channels. A large part of this debris would reach the lower basin. Much of the coarse debris would accumulate at the upstream end of the lower basin. Heavy flooding and local bank erosion would be expected.

(3) A period of light but steady precipitation would infiltrate and moisten the soil. This event, followed within a few weeks by record high rainfall from a series of closely spaced storms, would lead to the mobilization of large volumes of weathered rock and vegetation debris throughout the drainage system. Some of the massive landslides would become reactivated, contributing coarse debris and locally damming the trunk drainage courses. New bedrock landslides would locally occur due to the undercutting of the channel banks, but the main failures would be mudflows and debris flows. However, most of the rock debris would be carried off the steep slopes and into the channels by sheet flow. Unburned or partially burned stands of riparian vegetation would be undercut and transported along with weathered rock, soil and other vegetation. This material would stall locally in narrow reaches of the channels of the upper basin and at the junction of tributaries with main trunk drainages. The subsequent dams formed by the debris would eventually be overtopped or would fail and lead to surging in the flood waters downstream.

In the lower basin where the gradient of the river is relatively gentle, the floodplain would be deeply mantled with coarse debris (see diagrammatic sketch on map). As stream velocity lessens, the mix of coarse sediment, floating trees, and other vegetation would form jams among the trees growing in the floodplain, restricting or damming the stream flow.

### Flooding

The depth of the flood waters would be highest where the channel is normally narrow, or where it has been restricted by the building of alluvial fans across the channel out from tributary drainages (see map). These fans occur mainly at the junction of Pheneger, Juan Higuera and Pfeiffer–Redwood Creeks with the lower Big Sur River. Elsewhere, water levels will rise relatively higher where the river flows on top of sediments deposited during previous stages of the flood. Such a veneer of sediment, in effect, reduces the normal volume of the channel. During a one hour storm in El Dorado Canyon, Nevada, 12 feet of sedimentary debris was deposited and subsequent flood waters flowed on top of these sediments (Cleveland, 1975). Bank erosion would be common along the same reaches of the river as those of maximum flooding but also on the outside curve of the river where it normally makes broad bends within its channel.

## FLOOD HAZARDS

Conditions in the lower Big Sur basin pose a significant threat to life and property. Rainfall runoff that has collected over a total of 46 square miles must pass through a narrow funnel in places only a few hundred feet across. Rainfall may be moderate in the lower basin, while record runoff is collecting above. Even during periods of obvious flooding the river can be deceptive. Upstream the flow may be temporarily dammed by debris, lowering the flood levels along the lower reaches. If the debris gives way abruptly, a large volume of water may be suddenly forced through the lower channel. The channel area should not be occupied until a storm is known to have completely passed through the region and conditions in the upper basin have been evaluated.

This report was released by CDMG as Open File Report 77–12 LA "Analysis of erosion following the Marble Cone fire, Big Sur, Monterey County, California" by George B. Cleveland, August 1977, 13 pages, 1 plate (scale 1:39,600). Arrangements for copies of the original map can be made through a bonded blue print or reproduction service; reproducible master available in Los Angeles office only.

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# SEQUENTIAL CHANGES IN BED HABITAT CONDITIONS IN THE UPPER CARMEL RIVER FOLLOWING THE MARBLE-CONE FIRE OF AUGUST, 1977[1]

Barry Hecht[2]

Abstract.--Runoff following a major fire filled the upper Carmel River with sediment. Repeated measurements of four habitat descriptors were made in riffles during the three years after the fire. Habitat values were largely restored by the end of the first winter, with virtually complete recovery after three years.

## INTRODUCTION

The importance of episodic or unusual events in the management of riparian systems in montane areas is increasingly being recognized. Wildfires are one of the major recurring disturbances affecting biologic and geomorphic processes in these watersheds. This is especially true in basins with significant areas of steep, chaparral-covered slopes.

Many resource managers consider the canyon bottoms--the channels, riparian zones, and valley flats--as the most biologically-significant zones in these watersheds. The bottomlands commonly remain unburned during fires which otherwise affect much of the drainage area. The primary physical changes in these corridors are frequently those associated with erosion, deposition, and channel instabilities induced by post-fire storm runoff. While numerous studies of fire-related increases in runoff and debris load have been made, relatively little is known of their effects on habitat values.

This report is a preliminary summary of an ongoing study addressing one aspect of the larger management problem--the indirect effects of fires on bed conditions affecting aquatic habitat values. The upper Carmel watershed in Los Padres National Forest, Monterey County, California was chosen for this study for three reasons. First, the drainage is used primarily for recreational, habitat, and watershed purposes; the alluvial corridor is central to all three uses. Second, direct human disruption of soil and vegetation in the basin is minimal, limited primarily to ridgetops far removed from the channels. Third, the watershed is in the size range of the smaller basins capable of sustaining an anadromous fishery, which in the central coastal area of California is commonly considered to be from about 10 to 100 km.$^2$ (4 to 40 mi.$^2$).

There were two significant limitations on this study imposed by choice of the upper Carmel watershed. First, there are no stream gages in the basin. Synthesis of a flow-record for each site will be required to establish the relationship of the observed sequential changes to runoff. Data needed to develop the synthetic flow-record are presently not fully available. Secondly, access to the sites required a hike of about 8 km. (5 mi.) over damaged trails with backpacks and survey gear, limiting both the equipment which could be used and the number of sites which could be monitored during a given weekend.

## REGIONAL SETTING

The Carmel River drains the northern slopes of the Santa Lucia Mountains. The upper portion of the basin is a rugged area of approximately 161 km.$^2$ (62 mi.$^2$) above Los Padres Dam, a municipal water-supply source for the Monterey Peninsula urban area about 50 km. (30 mi.) to the north.

The watershed is underlain by faulted crystalline rocks, primarily schists, gneisses, and metasomatic granitic rocks ranging in composition from grandiorite to gabbro (Wiebe 1970). Weathering of these rocks produces a large amount of medium-grained sand, and a disproportionately small percentage of fine gravel. The courses of the main channels are structurally-controlled, primarily by faults and fractures. The channels are unusually steep for watersheds of comparable size in the region.

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[1]Paper presented at the California Riparian Systems Conference. [University of California, Davis, September 17-19, 1981].

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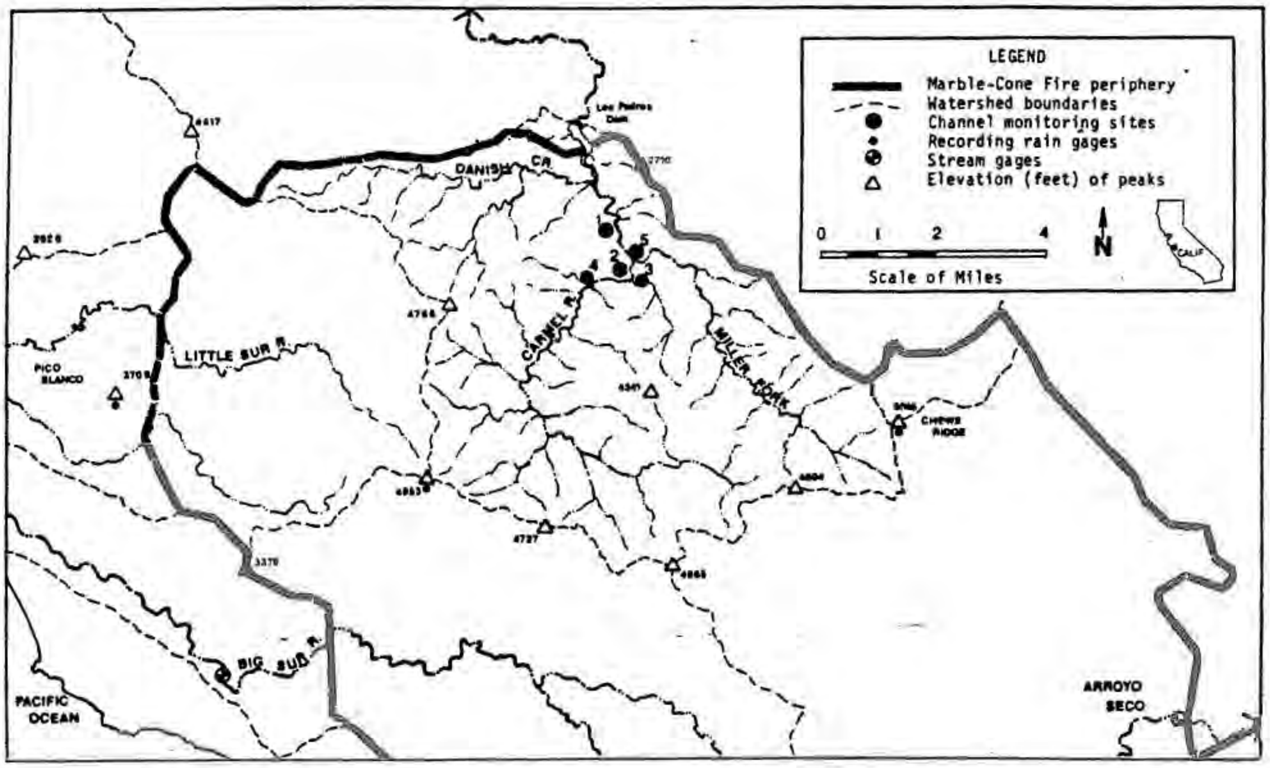


Figure 1.--Upper Carmel watershed and vicinity. Monitoring sites on the Carmel River are at Bluff Camp (1), Carmel Camp (2), below Bruce Fork (3), at Sulphur Springs Camp (4) and on Miller Fork above its mouth (5).

Rainfall ranges from an average of 610 mm. (24 in.) per year at Los Padres Dam to an estimated 1150 to 1270 mm. (45 to 50 in.) at the drainage divide with the Big Sur watershed. This supports a vegetative mosaic with chamise/chaparral on steeper exposed slopes, an oak/madrone woodland community on more protected slopes and terraces, and a mixed hardwood/coniferous forest at the highest elevations.

### The Marble-Cone Fire

The Marble-Cone Fire burned approximately 72000 ha. (178000 ac.) in the Santa Lucia Mountains during August, 1977. Virtually all of the Carmel watershed above Los Padres Reservoir was affected by the fire. The USDA Forest Service staff[3] estimated remaining canopy cover to be less than 10% in 42% of the upper Carmel basin, 11-50% over an additional 20% of the watershed, and more than 51% over the remaining 38% of the area. No extensive fires had occurred in the watershed during the previous 50 years. Much of the basin had remained unburned for 76 years or more (Griffin 1978).

[3]USDA Forest Service. Undated. Marble-Cone Fire: Remaining vegetative cover. Unpublished staff report. Los Padres National Forest.

Two unusual occurrences contributed to the severity of the burn, and particularly to its impact on the canyon floor areas. Fuel levels were abnormally high due to an extreme amount of limb breakage sustained during a wet and sticky snowfall on January 3, 1974. The effect on fuel loadings was especially large in the riparian zone, on the terraces, and lower slopes, areas seldom affected by snowfall. Secondly, conditions were also unusually dry following the severe drought of 1976 and 1977. Rainfall at Bug Sur, the nearest long-term station, during each of these years was less than that measured for any of the previous 58 years.

### Post-Fire Runoff

Rainfall during the 1977-78 and 1979-80 winter seasons was 40-50% above normal at many stations in the region; rainfall during 1978-79 was generally slightly below average. Reflecting both the above-average rainfall and the altered runoff characteristics, runoff in the Carmel and nearby watersheds was markedly above normal during this 3-year period (table 1). The duration of high flows was also much above normal. One measure of this duration is the number of days that flow exceeded bankfull conditions. In the Monterey Bay area (as in many other regions), this corresponds roughly to the flood with a recurrence of 1.5 years. The Big Sur River is the nearest gaged stream, and is considered most representative of the upper Carmel River. The 1.5-year flood discharge on the Big Sur River is approximately 1600 cubic feet per second (cfs). Based on preliminary records, this discharge was exceeded for a total of about 10 days in 1978 and about 6 days in 1980, compared with an annual average of 1.1 days for the period prior to the fire.

More specific data are available on the effects of the fire on sediment yields of the upper Carmel watershed (table 2). Deposition in Los Padres Reservoir during the 3 years following the fire was about equal to that occurring during the previous 30 years. In addition, a large but undetermined amount of debris has accumulated in the channels of the Carmel River and Danish Creek above the spillway elevation[4].

Table 1.--Post-fire runoff at gages in vicinity of the upper Carmel watershed.

| USGS gage no. | | 11143000 | 11143200 | 11151870 |
|---|---|---|---|---|
| Stream | | Big Sur R. | Carmel R. | Arroyo Seco |
| Location | | Big Sur - | Robles del Rio | nr. Greenfield |
| Period of record | | 1950-pres. | 1957-pres. | 1961-pres. |
| Drainage area (sq. mi.) | | 46.5 | 193 | 113 |
| Mean annual runoff | (cfs) | 89.6 | 71.3 | 121 |
| Runoff | | | | |
| 1978 | (cfs) | 246 | 206 | 378 |
| | (% of mean[1]) | 275 | 289 | 312 |
| 1979 | (cfs) | 97.9 | 63.5 | 163 |
| | (% of mean[1]) | 109 | 89 | 135 |
| 1980 | (cfs) | 200 | 192 | 295 |
| | (% of mean[1]) | 223 | 269 | 243 |

[1]Mean annual runoff through Sept. 30, 1977, excluding period of post-fire runoff.

## SEQUENTIAL CHANGES IN BED HABITAT CONDITIONS

Habitat in the streams of the upper Carmel system is generally evaluated by its suitability for salmonid production. The local resource includes both steelhead and resident trout. Availabilities of suitable spawning and rearing habitats are considered factors limiting both populations, a common situation in streams of central California.

In riffles of boulder-bedded streams such as the upper Carmel River, both spawning and rearing occur in spaces or openings between the larger bed-forming rocks. Spawning occurs in bars and accumulations of gravels which form between the boulders or in their lees, locations partially protected from scour.

Table 2.--Sequential sediment accumulation in Los Padres Reservoir[1].

| Survey date | Reservoir capacity[2] (acre feet) | Loss in capacity (acre ft.) | Annual rate of capacity loss (acre ft.) |
|---|---|---|---|
| Nov 1947[3] | 3200 | - | - |
| Nov 1977 | 2592.7 | 607.3 | 20.2 |
| Sep 1978 | 2037.6 | 555 | 555 |
| Oct 1980 | 1996.3 | 41.3 | 20.6 |

[1]Source: R. M. Bloyd[4]

[2]Below spillway elevation of 317.2 m. (1040.8 ft.) above mean sea level.

[3]From pre-construction capacity curves developed by California Water and Telephone Company.

The epicycle of massive fill and scour following fires in this environment temporarily buries most of the limited habitat with finer material, largely sand. For this reconnaissance study, descriptors chosen to define the extent of burial and subsequent uncovering of habitat include:

1. net fill and scour, as measured by level-surveys following each major group of storms;
2. particle-size distribution of the bed surface, measured by censusing particles at the intersections of a grid;
3. percentage of bed area occupied by sand and finer material, also sampled on a grid; and
4. percent of the bed covered by material of sizes suitable for spawning, determined as above.

### Net Fill and Scour

Minimal spawning or rearing habitat was available in the upper Carmel channels during the period of maximum fill. Habitat availability increased as the stored sediment was gradually scoured. A useful measure of these sequential changes is net mean fill or scour, determined from the change in mean bed elevation of the channel during each storm period. This change was quantified using repeated level-surveys of monumented cross-sections.

The sequence of fill and scour was recorded at 6 cross-sections in 3 riffles. The riffles were chosen shortly after the fire on the basis of observable habitat values for both spawning and rearing, their general alluvial character, absence of major unusual hydraulic properties, and presence in a long and straight reach. The last three criteria were necessary to meet the hydraulic requirement of the indirect discharge measurements used to determine the peak flows during each storm period. The sections were established in early November, 1977, following the fire but prior to

[4]Bloyd, R.M. Letter of March 18, 1981 to Robert F. Blecker, hydrologist for Los Padres National Forest, which summarizes U. S. Geological Survey studies of post-fire sedimentation in Los Padres Reservoir.

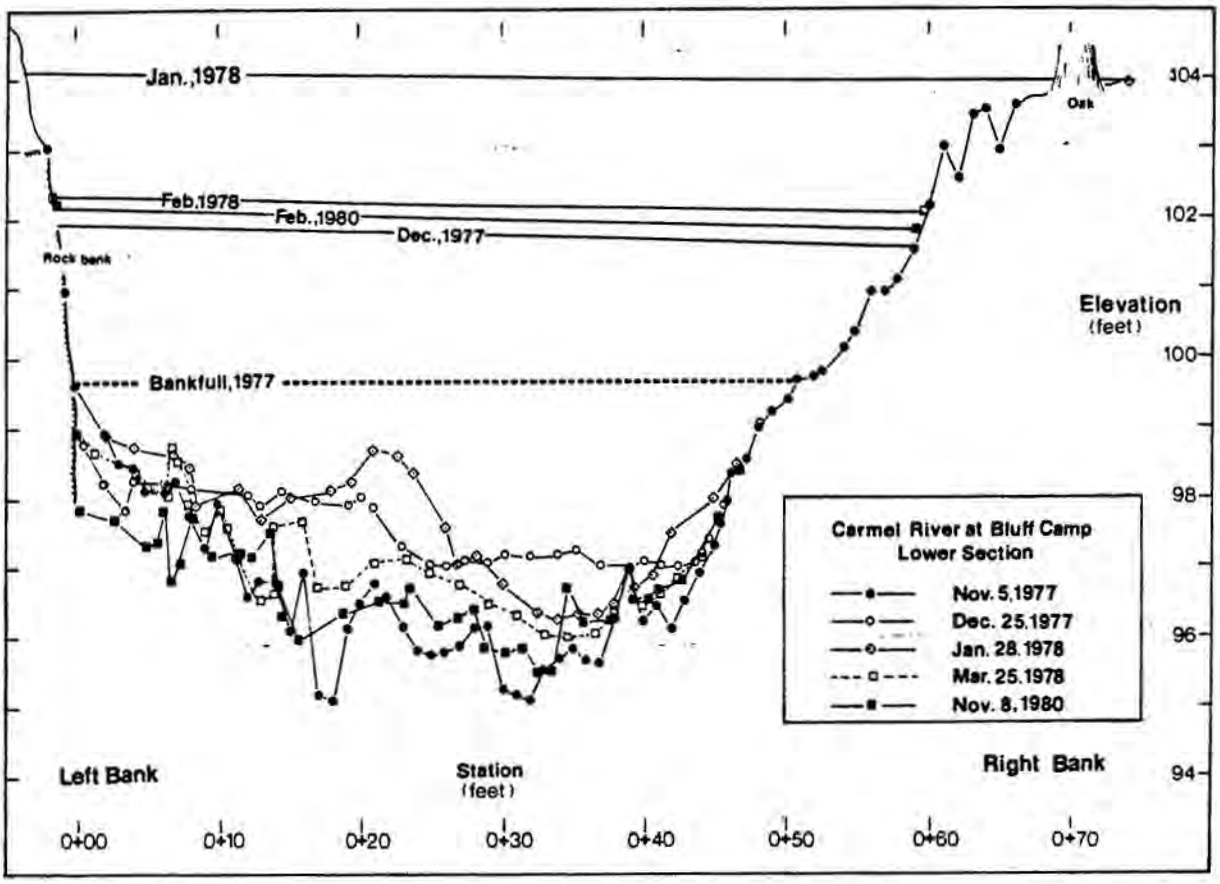


Figure 2.-- Bed configuration and high-water marks during the fill and scour cycle following the Marble-Cone fire. View downstream. Some high-water profiles slope toward the right bank, discussed below in the text.

any measurable runoff. Cross-sections were resurveyed after each significant flood event during the winter of 1977-78, and again following the wet season of 1979-80. An example of data collected at one section to describe the sequential changes in elevation and configuration of the bed is presented in figure 2.

The fill and scour cycle observed at each riffle is summarized in table 3. Fill occurred immediately after the first storms in December, 1977, and continued at some sections through the major storm period in January, 1978. By the end of the first winter, the bed was being scoured at all six sections, a process which continued through the second and third rainy seasons. The final column in the table traces the proportion of maximum net fill removed during each period.[5] By the end of the first season, 57-102% of the maximum observed net fill had been scoured. "Recovery percentages" of 80-151% were recorded by the end of the third year. At four of the six sections, 80-90% of the maximum observed fill had been removed by the end of the third year. Mean scour exceeding the mean maximum fill was limited to the riffle at Carmel Camp, where about half of the mean scour is attributable to lateral erosion of the lower bank area on one side of the channel.

### Size Distribution of Bed Material

The particle-size distribution of bed material is commonly quantified in the course of habitat assessments, either by a visual estimate or by a grid-by-number census. The latter approach was used in this study.

Particle-size distributions of bed-surface material were determined by measurement made at the

[5]Maximum fills may have been greater during one of the storm periods. Ephemeral bed conditions during storm crests may not have great importance in defining spawning or rearing habitat value; thus the methodology is appropriate for the purposes of this study. The reader is cautioned that recovery percentages in table 3 may under-estimate the removal of within-storm fill maxima.

same five riffles in the early fall months of each year, prior to the onset of rains. This is the season in which rearing habitat is most likely to be constrained by sediment. An area-stratified random sample of the entire riffle bed was drawn by stretching cloth measuring tapes between rows of 8 to 10 iron pins at the top and base of each riffle. Lengths of intermediate axes of particles immediately beneath pre-selected points on the tapes were measured and grouped in standard size-classes. This procedure is an adaption for use in boulder-bed channels of Wolman's (1954) now-standard methodology. A sample of 50 to 100 rocks is generally considered sufficient to describe bed-surface populations; larger samples were drawn following the 1978 storms as a wider range of size-classes was observed.

Sequential changes in the size distribution of bed material are shown in table 4. Sizes at the key descriptive percentiles generally decreased following the fire, then subsequently have

Table 3.--Sequential changes in net fill and scour.

| | | Mean Bed Elevation (ft.) | Net Fill(+) or Scour(-) (ft.) | Percent[1] Recovery |
|---|---|---|---|---|
| Carmel River at Bluff Camp | | | | |
| Lower Section | 11/05/77 | 96.82 | - | - |
| | 12/25/77 | 97.72 | +0.90 | - |
| | 01/28/78 | 97.83[2] | +0.11 | 0 |
| | 03/25/78 | 97.25 | -0.58 | 57 |
| | 11/08/80 | 96.93 | -0.32 | 89 |
| Upper Section | 11/05/77 | 99.48 | - | - |
| | 12/25/77 | 100.49[2] | +1.01 | 0 |
| | 01/28/78 | 99.89 | -0.60 | 59 |
| | 03/25/78 | 99.68 | -0.21 | 80 |
| | 11/08/80 | 99.68 | 0.00 | 80 |
| Carmel River at Carmel Camp | | | | |
| Lower Section | 11/06/77 | 93.82 | - | - |
| | 12/26/77 | 94.23[2] | +0.41 | 0 |
| | 01/28/78 | 94.00 | -0.23 | 56 |
| | 03/25/78 | 93.81 | -0.19 | 102 |
| | 11/09/80 | 93.61 | -0.20 | 151 |
| Upper Section | 11/06/77 | 95.24 | - | - |
| | 12/26/77 | 95.48[2] | +0.24 | 0 |
| | 01/29/78 | 95.40 | -0.08 | 33 |
| | 03/26/78 | 95.30 | -0.10 | 75 |
| | 11/09/80 | 95.15 | -0.15 | 138 |
| Miller Fork above Carmel R. | | | | |
| Lower Section | 11/06/77 | 91.50 | - | - |
| | 12/26/77 | 91.56[2] | +0.06 | 0 |
| | 01/29/78 | 91.56[2] | 0.00 | 0 |
| | 03/26/78 | 91.52 | -0.04 | 67 |
| | 11/09/80 | 91.51 | -0.01 | 83 |
| Upper Section | 11/06/77 | 94.18 | - | - |
| | 12/26/77 | 94.29 | +0.11 | - |
| | 01/29/78 | 94.53[2] | +0.24 | 0 |
| | 03/26/78 | 94.27 | -0.26 | 74 |
| | 11/09/80 | 94.23 | -0.04 | 86 |

[1] Defined as whole channel change in mean bed elevation (MBE) by the relation $100(MBE_m - MBE_i)/(MBE_m - MBE_o)$, with subscripts m, i, and o identifying maximum net fill, measured, and original post-fire conditions, respectively.

[2] Maximum net fill.

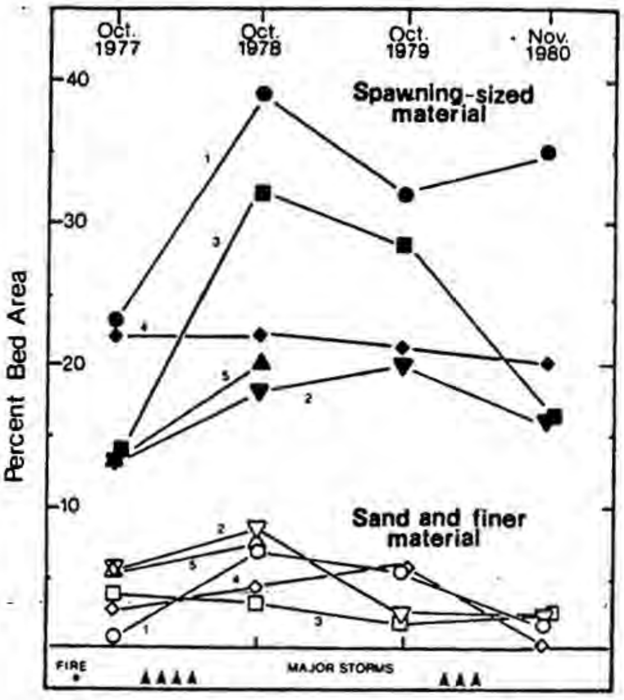


Figure 3.--Sequential changes in bed area occupied by spawning-sized material and sand-and-finer debris following the Marble-Cone fire. Run-off events substantially exceeding bankfull discharge are considered major storms. Sites are numbered as on figure 1 and table 4.

increased. Relative changes are more pronounced at the 16th and 50th percentiles than in the larger material, as might be expected.

Much and probably most, of the change in particle-size distribution occurred during the first year following the fire. It was not feasible to re-census the bed between storms to the unusually high flows of the winter of 1978. In most cases, the minimum sizes probably were associated with the December, 1977 or January, 1978 storm periods. Had no more storms occurred during the winter of 1978, a much greater effect on habitat conditions would have been observed during the summer and fall of 1978.

## Sand-Covered Bed Areas

Aquatic biologists have often identified percent bed area covered by sand (or finer material) as a significant influence on the distribution of species in the channel, and as a factor affecting salmonid egg viability. The distribution of sand and finer material on the bed of mountain stream riffles appears to be controlled by different geomorphic processes than those governing the coarser sizes. In this study, sand is considered as a separate population, one whose variability is also best described by the percentage of the riffle bed

Table 4.--Sequential changes in particle-size distribution of bed material, upper Carmel Watershed

| Site No. | | 1 | | | | 2 | | | | 3 | | | | 4 | | | | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stream | | Carmel River | | | | Carmel River | | | | Carmel River | | | | Carmel River | | | | Miller Fork | |
| Location | | at Bluff Camp | | | | at Carmel Camp | | | | below Bruce Fork | | | | at Sulphur Springs Camp | | | | above mouth | |
| Month/Year | | 10/77 | 10/78 | 10/79 | 11/80 | 10/77 | 10/78 | 10/79 | 11/80 | 10/77 | 10/78 | 10/79 | 11/80 | 10/77 | 10/78 | 10/79 | 11/80 | 10/77 | 10/78 |
| Lower limit of size class | | | | | | | | | | | | | | | | | | | |
| Boulders | 2050 mm. | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | |
| | 1450 | 1 | 2 | 3 | 5 | | 1 | | 1 | 1 | 1 | 1 | 5 | | | | | | 1 |
| | 1024 | 3 | 2 | 3 | 8 | 4 | 5 | 1 | 1 | 3 | 1 | 1 | 3 | | 2 | | 2 | 3 | 3 |
| | 725 | 6 | 2 | 11 | 9 | 10 | 6 | 2 | 3 | 6 | 3 | 2 | 8 | 2 | 2 | 2 | 5 | 8 | 6 |
| | 512 | 8 | 5 | 17 | 9 | 13 | 17 | 19 | 15 | 8 | 6 | 12 | 11 | 7 | 14 | 13 | 8 | 6 | 7 |
| | 360 | 7 | 6 | 14 | 12 | 18 | 13 | 17 | 23 | 6 | 7 | 14 | 12 | 8 | 15 | 12 | 17 | 7 | 7 |
| | 256 | 11 | 7 | 12 | 13 | 16 | 10 | 16 | 23 | 6 | 15 | 10 | 18 | 10 | 16 | 18 | 11 | 14 | 7 |
| Cobbles | 180 | 7 | 7 | 14 | 9 | 6 | 13 | 14 | 14 | 7 | 17 | 17 | 16 | 2 | 16 | 15 | 20 | 12 | 12 |
| | 128 | 6 | 10 | 18 | 9 | 2 | 7 | 19 | 12 | 6 | 9 | 11 | 16 | 10 | 14 | 14 | 15 | 12 | 9 |
| | 90 | 4 | 9 | 18 | 12 | 1 | 5 | 12 | 14 | 3 | 5 | 13 | 11 | 7 | 12 | 14 | 10 | 9 | 7 |
| | 64 | 1 | 7 | 15 | 10 | 2 | 4 | 12 | 9 | 3 | 9 | 5 | 7 | 5 | 10 | 4 | 12 | 3 | 8 |
| Pebbles | 45 | 3 | 7 | 11 | 13 | 2 | 5 | 3 | 2 | - | 9 | 7 | 4 | - | 7 | 8 | 7 | 3 | 4 |
| | 32 | 2 | 6 | 10 | 6 | 1 | 5 | 2 | 2 | 1 | 3 | 9 | 3 | 1 | 3 | 6 | - | 1 | 5 |
| | 22.6 | 1 | 6 | 7 | 7 | 1 | 3 | 2 | 2 | - | 5 | 4 | 1 | 1 | 3 | 1 | 1 | - | 4 |
| | 16 | 2 | 4 | 3 | 5 | 2 | 1 | 2 | 2 | 1 | 3 | 2 | 2 | 4 | 1 | 2 | 1 | 2 | 3 |
| Fine Gravels | 11.3 | 2 | 1 | 3 | 2 | 1 | - | 1 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | - | 1 | 2 |
| | 8 | 2 | 1 | 4 | 1 | 1 | - | 3 | 1 | 1 | 1 | - | 1 | 1 | - | 2 | - | 1 | - |
| | 5.6 | 2 | 3 | 1 | - | 1 | 1 | - | 1 | - | - | 1 | - | 1 | 1 | 1 | 1 | - | 1 |
| | 4 | 1 | 2 | 2 | - | - | - | - | - | - | 1 | - | - | - | 1 | - | - | - | 1 |
| | <4 mm.[1] | 1 | 6 | 9 | 2 | 5 | 9 | 3 | 3 | 2 | 3 | 2 | 3 | 3 | 5 | 7 | 0 | 5 | 6 |
| Totals[2] | | 70+1 | 88+6 | 167+9 | 130+2 | 81+5 | 96+9 | 125+3 | 127+3 | 54+2 | 96+3 | 111+2 | 119+3 | 60+3 | 118+5 | 113+7 | 112+0 | 82+5 | 89+6 |
| Percentile size (mm.)[3] | | | | | | | | | | | | | | | | | | | |
| | $d_{84}$ | 710 | 494 | 606 | 783 | 751 | 676 | 531 | 510 | 984 | 412 | 490 | 658 | 499 | 502 | 468 | 482 | 541 | 587 |
| | $d_{50}$ | 273 | 118 | 154 | 184 | 395 | 294 | 213 | 266 | 304 | 188 | 187 | 242 | 175 | 206 | 196 | 212 | 231 | 174 |
| | $d_{16}$ | 39 | 27 | 40 | 45 | 151 | 66 | 78 | 88 | 97 | 48 | 45 | 64 | 67 | 68 | 56 | 80 | 98 | 40 |
| Fines abundance[4] (% bed area) | | 1.4 | 6.8 | 5.1 | 1.5 | 5.8 | 8.6 | 2.4 | 2.4 | 3.6 | 3.0 | 1.8 | 2.5 | 4.8 | 4.1 | 5.8 | 0.0 | 5.7 | 6.3 |
| Spawning material abundance[5] (% bed area) | | 23 | 39 | 32 | 35 | 13 | 18 | 20 | 16 | 14 | 32 | 28 | 16 | 22 | 22 | 21 | 20 | 13 | 20 |

[1]4 mm. is considered the lower limit for size class discrimination under field conditions. Division between sand and gravel usually taken at 2 mm.
[2]Expressed as total rocks + total sand and finer material (<4 mm.).
[3]Size, in millimeters, of material, coarser than 84, 50, and 16 percent of the sample.
[4]Percentage of bed area covered by material finer than 4 mm.; in the upper Carmel basin, this is mainly medium sand.
[5]Percentage of bed area occupied by material of 4 - 90 mm. (see text).
[6]Bed-surface distribution clearly altered by large limb from diseased oak which fell into channel during 1979. Monitoring discontinued.

which it covers. In this study, the sand-and-finer percentage of the bed surface was determined in the course of the particle-size measurements. Intermediate axial lengths of particles smaller than 4 mm. could not be readily measured under field conditions; these were grouped in a single class informally labelled as "fines."[6]

Sequential changes in the sand-covered proportion of the bed are shown in figure 3. The fines abundance increased markedly with the first storms after the fire. At the Bluff Camp riffle, the percentage of bed area covered by sand or finer debris on December 25, 1977, was visually estimated to be 40% in the riffle and 95% in the pool beneath it. By the end of the first year, the fines abundance at the five sites averaged only very slightly greater than at the time of the fire. As with the particle-size changes, the sequential variations in fines abundance were greatly accelerated by the unusually high runoff conditions of the 1978 water year.

### Availability of Spawning-Sized Material

Salmonid spawning habitat in the upper Carmel watershed may be limited by the availability of material of suitable sizes in riffles. The relative abundance of this material can be quantified for the Carmel channels as the percentage of the bed surface occupied by rocks within the range of

[6]Most standard classifications divide sands and gravels at 2 mm. In the upper Carmel environment, deficient in very fine gravels, any interpretive difficulty introduced by including 2-4 mm. material with the sands is minor.

suitable sizes, as no appreciable armoring of the bed was observed. For this study, it is assumed that the range of 4-90 mm. defines the bulk of material found in and above freshly-constructed redds in streams of comparable size, slope, and underlying rock types (e.g., Orcutt et al. 1968, Platts et al. 1979).[7]

The availability of spawning-sized material increased markedly at 4 of the 5 riffles in the first year after the fire. The percentage of the bed occupied by this size-range has remained slightly elevated, although depletion has probably occurred since 1978, particularly in the smaller sizes. To an appreciable degree, the increase has been manifested as expanded bars in the lees of large boulders, a location preferentially used for spawning in boulder-bedded channels. The role of fires in the supply of gravels in high-gradient streams merits study.

## SUPPLEMENTAL OBSERVATIONS

Other processes related to post-fire sedimentation also affected the channels and riparian corridors. These were observed in a more general way.

1. The fill and scour cycle in pools and in glides (or "runs") was greater in absolute magnitude than in riffles. Several traditional swimming holes were completely filled during the December and January storms following the fire. The relative rates of recovery in pools and glides seemed to be similar or slightly slower than those occuring in the riffles of this boulder-bedded channel.

This study was limited to describing sequential changes in riffles, where indirect discharge estimates and bed-material census are customarily made. Equally important in this decision was the historical emphasis on riffles by aquatic biologists. Subsequent research has clarified and quantified the importance of rearing habitat within pools and glides in salmonid production (e.g., Bjornn et al. 1977; Kelley and Dettman 1979). Future studies of post-fire changes in habitat should include pools and glides.

2. Few secondary slope instabilities were induced by the fire. Landslide-related sediment delivery to the main channels was probably of negligible magnitude, probably contributing to the rapid rate of sediment depletion in the channels. The relative stability of the slopes is considered to be primarily a function of bedrock type.

3. Interception of sediment on the lowermost terrace was widespread, particularly at the mouths of ravines, chutes, and small tributaries. Much of this material is of gravel or pebble size. Relative to the volume of coarse material deposited in and above Los Padres Reservoir since the fire, the volume of debris intercepted on the terrace was small, perhaps 1 to 3%. This proportion is smaller, but of a similar order of magnitude, to the fire-related sediment still stored in the main channels at least above the tailwater areas of Los Padres Reservoir. Delayed delivery of coarse material stored in these debris cones may be a factor in maintaining the supply of spawning-sized material during extended periods between major fires and floods.

4. Floods following the fire removed much of the organic matter which had accumulated in the channel. Most fallen trunks and limbs on or spanning the bed were dislodged, then either washed through to Los Padres Reservoir or wedged between the trunks of the larger riparian trees distributed along the banks. These small debris jams generated significant eddies during flood periods. As an example, the high-water marks of the December, 1977, February, 1978 and February, 1980 floods indicate that the water-surface profile sloped toward the right bank, the result of a small debris jam 12 m. (40 ft.) upstream. Nearly continuous lines of broken twigs and other fine organic matter accumulated in the eddies during each storm. Each line contained an appreciable amount of material, generally 0.5 to 5 cm. in thickness. Partial incorporation of this material into the soil was clearly visible by November, 1980. Post fire addition of organic material to soils at or slightly above the active flood plain may be an appreciable factor in the development of soils in the riparian zone.

## CONCLUSIONS

1. Sequential changes in riffle conditions in the upper Carmel watershed following the Marble-Cone Fire were observed using 4 physical descriptors of salmonid habitat:
   a. mean fill and scour;
   b. particle-size distribution of the bed surface;
   c. percent of the bed surface covered by sand and finer debris;
   d. percent of the bed surface occupied by material of sizes suitable for spawning.

2. Riffles in the master channels of the upper Carmel watershed filled up to 1 foot during the first storms following the Marble-Cone fire, primarily with sand. By the end of the first year, most of the fill had been scoured; much of what remained was of pebble and cobble size. By the end of the third year, all descriptors had returned to within 20% (relative to the maximum measured distruption) of their pre-fire conditions. Other on-going watershed processes were probably more important than residual effects of the fire as

[7] Percentages of bed area occupied by material of other ranges may be computed from table 4 by those who would prefer to consider different sizes.

influences on habitat conditions by the end of the third year.

3. Effects of the fire on runs and pools were not measured. Maximum mean channel fill was generally observed to be several times greater than in riffles. Recovery of habitat values appear to occur at relative rates that were similar to or slightly slower than those in the riffles.

4. A substantial volume of sediment, primarily gravels and cobbles, was intercepted in the riparian and terrace acreas. Delayed delivery to main channels is likely to be an important factor in maintaining the availability of spawning-sized material between major disruptive events.

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