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MEMORANDUM

DATE: NOVEMBER 2, 2020

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FROM: Jeremy Lancaster (CGS – Team Coordinator)
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SUBJECT: Boulder Creek Post-WERT Study
2020 CZU Lightning Complex Burn Area, Santa Cruz County

Cal OES Mission #:
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Deployment Date:
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1.0 INTRODUCTION AND BACKGROUND

The CZU Lightning Complex started as a series of lightning fires on August 16, 2020 across western Santa Cruz and San Mateo counties. The fire was fully contained on September 22, 2020, including a total 86,509 acres burned, with 1,450 structures lost and one fatality. A Presidential Major Disaster Declaration for fires in California ignited by the August 2020 lightning storm includes the 2020 CZU Lightning Complex fire. Due to its proximity to developed areas and critical infrastructure, the burned area was evaluated by an interagency Watershed Emergency Response Team (WERT). The area burned by the CZU Lightning Complex is composed of various types of ownership, including federal, state, non-profit, and private landholdings. The WERT performed a rapid field evaluation of the burned area from August 28, 2020 to September 5, 2020, with additional field work occurring on September 11, 2020. The WERT rapidly evaluated post-fire watershed conditions, soil burn severity, identified potential **Values-at-Risk (VARs)** related to human life-safety and property, and evaluated the potential for increased hazards of rockfall as well as post-fire flooding and debris flows. The team also recommended potential emergency protection measures to help reduce the risks to those values.

Most of the CZU lightning complex Fire area had not burned within recent recorded history. The largest previous fire within the burned area was the 2009 Lockheed Fire, where approximately 8.8 percent of the CZU burned area. The WERT team found that 43 percent of the burned area is composed of moderate (34.1 percent) to high (9.1 percent) soil burn severity. The validated Soil Burn Severity (SBS) map was submitted to the U. S. Geological Survey (USGS) post-wildfire landslide hazards group, where models of potential debris flow probability and volume were generated for the CZU Lightning Complex Fire on September 1, 2020 (USGS, 2020). This modeling indicates a moderate to high probability for debris flows in the major canyons within the burn area under expected rainfall intensities, and for generation of substantial volumes of debris.

The WERT team evaluated sub-meter LiDAR hillshade imagery (Tukman Geospatial, 2020) of the burned area. Alluvial fan and debris fan geomorphology were observed at the mouths of drainage basins along the State Route 9 just east of the fire perimeter. While the USGS indicates that the burned watersheds in this area have very low to low probability in this region, the presence of alluvial fans and boulder strewn stream deposits suggests a history of sediment laden and debris flows. Because of the increased potential for debris flows and flooding under post-fire conditions and the presence of extensive residential, commercial, and municipal development on alluvial fans down-slope of the burn area that are located on alluvial fans, the WERT team identified potential Values-at-Risk (VARs) based on the fan geomorphology.

In total the WERT identified 111 VARs and presented a summary of findings to Santa Cruz and San Mateo Counties personnel at close-out meetings on September 9 and 10 to assist in the counties' initial response planning efforts. The WERT report was finalized on October 8, 2020 (CAL FIRE, 2020). Most of the VARs identified by the WERT are within Santa Cruz County, and a significant number of those are along the Highway 9 and 236 corridors encompassing Boulder Creek and neighboring communities. **The October 8, 2020 WERT Report provides much of the base information used in this Post-WERT Mission Task Study, and should be used in conjunction with this Post-WERT report. Due to the very rapid nature of the WERT assessment, it was not possible for the WERT team to rapidly evaluate all geologic and hydrologic hazards, or predict potential flow paths on alluvial fans. Therefore, Santa Cruz County requested additional assistance through CalOES for CGS to conduct a more focused rapid evaluation of alluvial fan geomorphology and prepare maps illustrating areas in and near Boulder Creek potentially subject to high and low energy debris flow and flood inundation, to be completed prior to the onset of the winter rain season. The CalOES Mission Task was delivered to CGS on September 28, 2020. Figure 1 shows the CZU burn perimeter relative to the study area that we report on herein.**

1.1 Purpose and Scope

The study area (Figure 1) for this evaluation focuses on slopes that drain the eastern flank of Ben Lomond Mountain and includes communities along State Routes 9 and 236 from Brookdale in the south to Forest Springs in the north. Many of the communities in the study area are built on alluvial fans observed in sub-meter LiDAR hillshade imagery (Tukman Geospatial LLC, 2020) and it was beyond the scope of the rapid WERT evaluation to further refine potential debris and flood flow paths. In response to the CalOES Mission Task request 2020-SOC-42611, CGS assembled a team with a background in geomorphology, alluvial fan geomorphic evaluation, debris and sediment-laden flow hazard assessment, and GIS support personnel, to conduct the requested assessment in close coordination with representatives from Santa Cruz County Planning Department including the Chief of Flood Control and the County Geologist.

In this study we use the following definitions:

> Alluvial Fan - An alluvial fan is a sedimentary deposit located at a topographic break that is composed of fluvial and/or debris flow sediments and that has the shape of a fan either fully or partially extended (NRC, 1996).
>
> Sediment-laden Flows - Runoff containing suspended and bedload sediment.
>
> Debris Flow – A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope.
>
> Debris Fan – A debris fan is an accumulation of deposits dominated by debris flow and colluvial deposition, having a shape of a fan either fully or partially extended.
>
> Avulsion - A sudden cutting off or separation of land by a flood or by an abrupt change in the course of a stream [or debris flow], as by a stream breaking through a meander or by sudden changes in current, whereby the stream deserts its old path for a new one (NRC, 1996).

The effects of the CZU fire on watersheds draining Ben Lomond Mountain toward Boulder Creek study area can be two-fold during watershed recovery. The fire's consumption of organic litter, duff, understory shrubs, shallow root systems, and reduction of overstory canopy can lead to increased runoff and the initiation of rills and gullies on steep sloping terrain, resulting in sediment-laden flows and runoff-initiated debris flows. Additional fire related factors that may enhance debris flow initiation include dry-ravel, preexisting landslides, marginally stable slopes particularly adjacent to stream channels, and downed trees. Where present, these additional phenomena increase debris flow likelihood and volume. Watershed recovery in the study area may take about 2-5 years, but will be dependent upon the speed of vegetation reestablishment, including shallow and deep root systems.

In addition, the fire effects on shallow root systems and soil structure may also enhance the mobilization of shallow landslides (e.g. debris slides) due to the disaggregation of soil and the loss of root cohesion, or root strength. Shallow landslides can mobilize as debris flows with long runout distances, and impact downslope infrastructure, property and pose life-safety threats. Additionally, as in unburned conditions, high seasonal rainfall totals have the potential to increase both shallow and deep landsliding, burned conditions increase this potential.

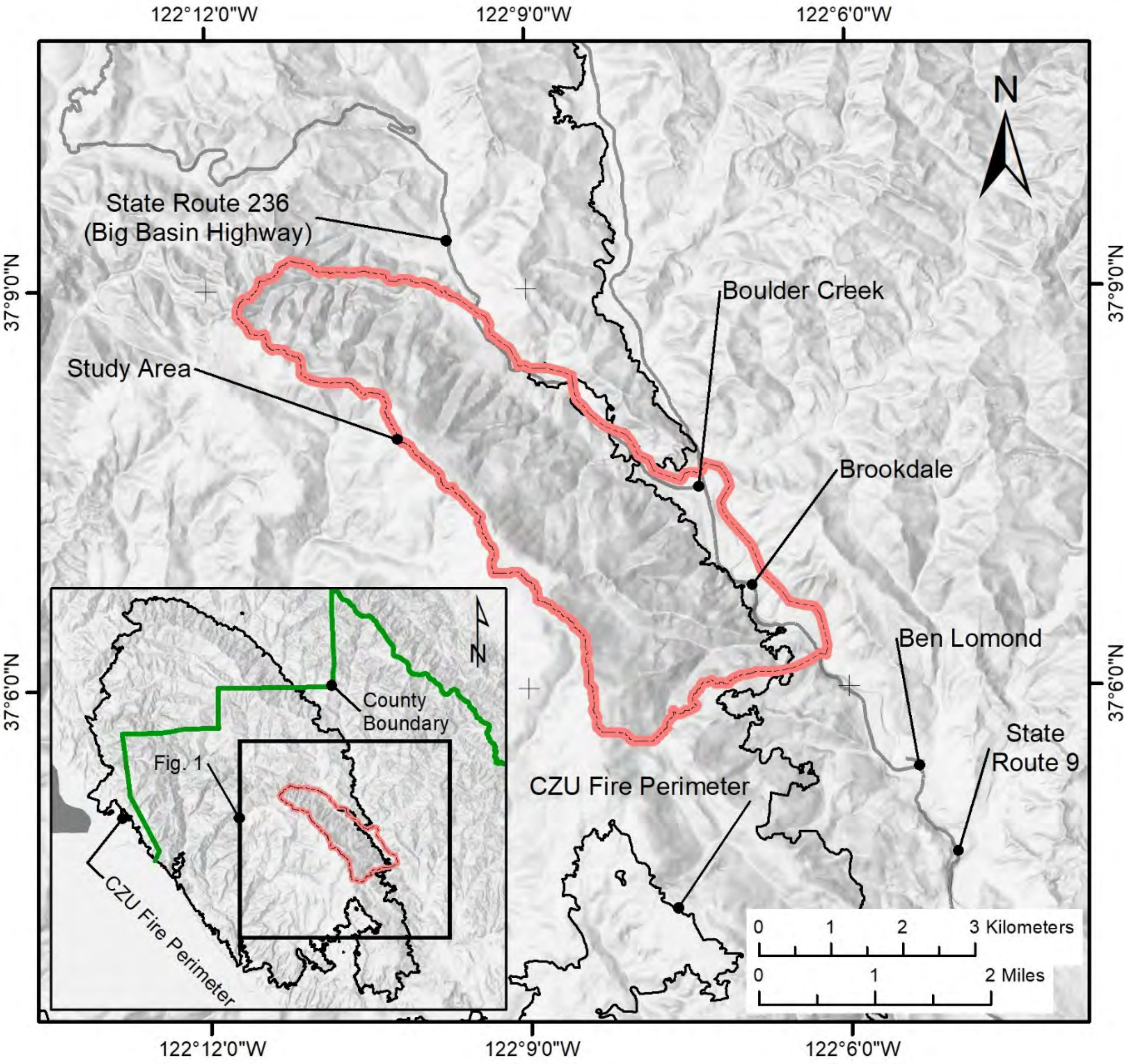

Figure 1. Overview map showing the study area in this debris flow hazard assessment.

This rapid evaluation focuses on the runoff-driven effects of wildfire during intense winter storms but also provides limited considerations for shallow landslide driven debris flows in steeply sloping terrain both upstream and adjacent to the built environment.

1.2 Scope

The following scope of work was developed in consultation with the County of Santa Cruz:

Task 1: Conduct a review appraisal of existing available data and prepare preliminary geomorphic interpretation and mapping of alluvial fan landforms. This task includes the following subtasks:

- Interpretation and mapping of alluvial fan landforms
- Review of channel networks and geometry
- Review of watershed debris flow history
- Review of hydrology data

Task 2: Review and provide input to preliminary hazard mapping developed with Santa Cruz County, including the following subtasks:

- Field Evaluation of Soil Burn Severity (SBS)
- Refine existing WERT SBS map data if necessary
- Avulsion evaluation, including preliminary identification and mapping of channel choke points

Task 3: Rapidly map the potential extent of debris flows and sediment-laden floods within and down gradient of the CZU Fire burn perimeter within the Boulder Creek study area, including the following subtasks:

- Distribution, age, and type of alluvial fan deposits.
- Identification and position of alluvial fan topographic apices, and possible hydrographic apices.
- Identify the presence of features on the landscape suggestive of past debris flow activity.
- Map and catalog “accessible” locations that may impact the conveyance capacity of local channels (i.e. channel constrictions or “choke points”).
- Consider storm event-based scenarios developed for downstream urbanized areas.
- Assist Santa Cruz County in the development of a decision matrix based on four levels of risk tiered to four different triggering rainfall events that could be used to support operational response decisions.
- Prepare this project report and mapping products.

Task 4: Monitoring coordination, including the following subtasks:

- Identify potential rain gage locations and work with local and state government to install additional telemetered and tipping bucket rain gages.

- Identify potential stream gages locations and work with local and state government to install stream stage recording equipment.
- Assist county and local personnel with implementing a post-storm monitoring plan.

Preliminary office-based geomorphic interpretation and mapping of alluvial fans and debris fans in the study area was conducted prior to deployment of field teams utilizing LiDAR hillshade imagery (Tukman Geospatial LLC, 2020). Reconnaissance field work was conducted from September 29 to October 3, 2020. An overview of the regional landslide history, landslide and flooding photos, and aerial photo review observations are attached in Appendix A through C, respectively. The results of the above listed tasks are included in this report and its associated attachments.

Work conducted under Task 2 included the identification and mapping of channel constrictions where avulsions may occur during storm events and to qualitatively delineate approximate areas of potential deposition and impact by high and moderate energy flows. Quantitative modeling of potential flow paths was not a part of the scope of work. Procedures for this task include:

- Use of Lidar derived hillside imagery to interpret and locate alluvial fans, debris fans, and shallow seated landslides.
- Review historic aerial photography and google earth imagery to help evaluate geomorphic expression of past flood and debris flow events in order to characterize flood and debris flow activity.
- Review of available historic photographs and locations where manmade alterations may influence flow paths of debris flows.
- Map and catalog channel constrictions (natural or manmade) or bends that may limit, or block, the conveyance capacity of local channels, which could force future flows out of their channels (avulsion) and generate debris flows and debris-laden flooding away from established flow paths.
- Review conveyance capacity of existing channel cross sections, particularly at constriction locations.
- Prepare maps illustrating areas subject to potential high and low energy flows.

The purpose of this rapid assessment is to provide a general understanding of the potential extent of debris flow and sediment-laden flow inundation and impacts based on geomorphic indicators, historic accounts of past flood events, and post-fire conveyance capacity of local channels.

Concurrent with the preparation of the qualitative high and moderate energy map, CGS provided assistance to Santa Cruz County emergency management personnel and CalOES in the development of a decision matrix based on four levels of risk tiered to four different triggering rainfall thresholds that could be used by emergency response managers and personnel to develop appropriate operational needs and logistics. The rainfall thresholds in this matrix were based on post-fire response thresholds from historical fires in the region, including the Big Sur area that has similar geoclimatic conditions as the CZU complex, historical rainfall information from large storm events in the Santa Cruz area, debris flow thresholds identified by the USGS for the CZU lightning complex Fire, and input from the NWS and from Santa Cruz County.

1.3 Topography, Regional Geology, and Faulting

The study area is situated east of Ben Lomond Mountain, northwest of the City of Santa Cruz, in the Coast Ranges geomorphic province (CGS, 2002). The study area lies within the eastern portion of the CZU complex burned area and includes several east to southeast-flowing watercourses that outlet onto developed alluvial and debris fan surfaces. Most of the study area is underlain by Mesozoic granitic basement rock (Kqd) fringed with Tertiary age sedimentary bedrocks in the northern portions of the study area (Tbl, Tl, Tss, Tvq), and Tertiary age rocks (TM, Tlo) and Quaternary age alluvial derived deposits (Qal) along the eastern margin of the study area (Brabb and others, 2000, Figure 2).

The northwest-southeast structure of the Coast Ranges is controlled by a complex of faults within the San Andreas Fault system, including the San Gregorio, Zayante-Vergeles, Butano, and Ben Lomond faults, which are identified within and/or immediately adjacent to the CZU complex burned area (Jennings and Bryant, 2010; Stanley and McCaffrey, 1983). No active faults are mapped within the study area (Jennings and Bryant, 2010).

The Ben Lomond Fault, a subsidiary fracture within the San Andreas Fault system, is not considered active within the past 85,000 years (Stanley and McCaffrey, 1983). However, the Ben Lomond Fault trends along San Lorenzo River Valley which supports the communities of Felton, Ben Lomond, and Boulder Creek (Brabb et al., 2000; Stanley and McCaffrey, 1983). The Ben Lomond Fault has a near vertical slip surface; slopes immediately upslope to the west of Boulder Creek are steep and composed of granitic basement rock that is heavily fractured, jointed, and shattered (Stanley and McCaffrey, 1983) as a result of movement on this and adjacent faults.

The east-flowing watercourses that drain into Boulder Creek and the San Lorenzo River are 3 to 4 times steeper than watersheds in the other portions of the CZU burned area and are characterized as high energy watersheds depositing granitic boulders and forming a knick point in the San Lorenzo River (Finnegan, 2017).

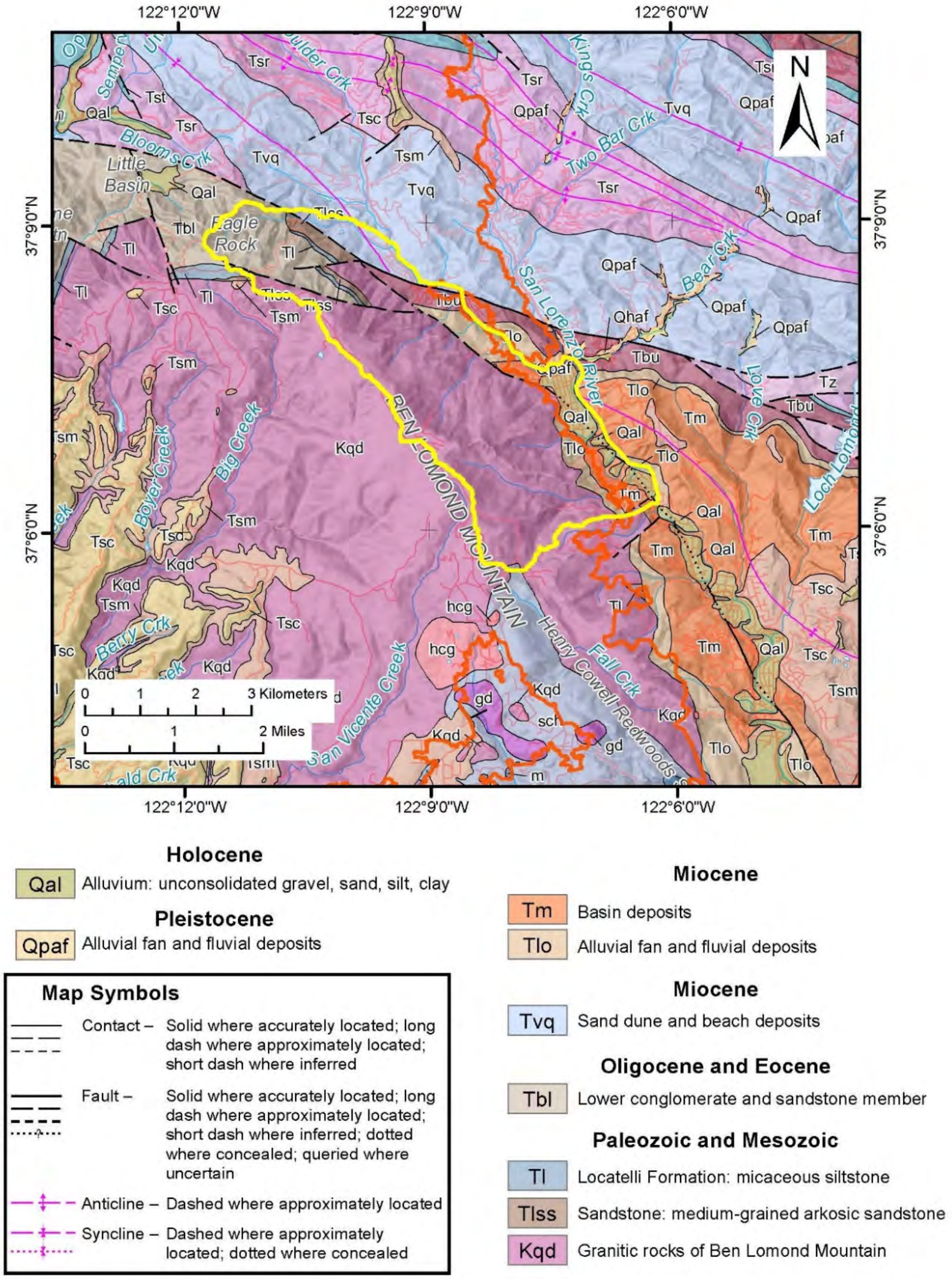

Figure 2. Regional Geologic map showing the study area in this assessment (from Brabb, et.al., 2000).

1.4 Fire-induced Impacts on Runoff

1.4.1 Flash Floods and Debris Flows

Vegetation on natural unburned slopes supports and protects the soil through root structure, a litter and duff covered surface that acts to reduce raindrop impact and soil detachment, interception of rainfall, and evapotranspiration. All these factors together reduce the availability of water to generate runoff. When the vegetation is burned during wildfires, the benefits provided by the vegetative cover are lost or reduced and runoff in the watershed is increased, both in overall streamflow volume and peak flow. Thus, post-fire flows are flashier than normal with more frequent flood events, especially in the first two to five years following a fire (Cannon et al., 2008; USGS, 2005). For this reason, post-wildfire runoff can be disproportionately large for the size of the watershed (Moody et.al., 2013).

In general, the denser the pre-fire vegetation and the longer the fire residence time, the more severe the effects of the fire are on soil hydrologic function. This is because aside from consuming vegetation and vegetative litter, fire can promote the formation of water repellent layers at or near the surface of soils which subsequently increases runoff. The two primary ways in which soil infiltration is affected by fire is by soil sealing and the creation of water-repellent (hydrophobic) soils near the surface. Soil sealing is caused by the infilling of surface voids in the soil by fine-grained clay and ash exposed and mobilized by raindrop impact after fire (Larsen et al., 2009). Hydrophobic soils are caused by the creation of a waxy substance that coats soil particles near the surface as hot vapors generated by the burning of organic matter condense in the cooler soils Parsons et al. (2010). Fires can also disaggregate shallow soil particles, forming a mantle of cohesionless mixture of ash, sand, and gravel. This material is subject to dry ravel processes (the rolling, bouncing, and sliding of individual particles down a slope) on steeper slopes and results in increases susceptibility to surficial erosion both by rain and wind (e.g. Lamb et al., 2011). This material may be entrained by runoff, increasing the density and viscosity of the fluidized matrix, enabling the initiation of debris flows.

1.4.2 Soil Burn Severity

To more rigorously assess post-fire effects on the vegetative cover, ground cover, and soil infiltration capacity within the study area, our team performed over 15 soil burn severity (SBS) observations and tests following procedures outlined in Parsons et al (2010). Results of our assessment largely corroborated earlier work done by the WERT within the low, moderate, and high SBS classifications throughout the fire. However, we found areas mapped within the study area as very low/unburned fall within the “low” SBS category. Thus, our evaluation found the soil burn severity map shown in the WERT report to be accurate at moderate and high burn severities, which are known to be most sensitive to increased runoff potential, but generally underrepresented the current study area impacts at low SBS. Our field observations indicate that almost 80% of the slopes within the study area upgradient of values at risk are characterized as having low SBS. Under low soil burn severity the following representative conditions were observed:

- understory is mostly consumed, but the overstory canopy was intact with a mosaic of mostly green foliage with some unchanged but brown foliage due to convective heat,

- duff layer is partially to moderately consumed reducing it from multiple inches to a 1- to 2-inch thick layer of partially burned organic litter covering most of the mineral soils,
- mineral soil structure is intact with fine roots mostly undamaged, and,
- soil infiltration rate is reduced, as determined using waterdrop infiltration tests.

The remainder of slopes are burned at mostly moderate (17.5 %) with some high (1.9 %) soil burn severity. These slopes are generally located along ridge tops and on south-facing aspects at high elevations within the basins that drain toward values at risk. Moderate to high soil burn severity generally consists of fully scorched to consumed canopy, fully consumed duff layer, and altered soil structure resulting in single-grain detachment with moderate hydrophobic conditions observed. Dry ravel of loose sediment is prominent on steep slopes burned at moderate and high severity. Table 1 provides a percent breakdown of soil burn severity in areas within the study area upslope of values at risk.

% Total Unburned/Very Low	% Low	% Moderate	% High
1.4	79.2	17.5	1.9

Table 1. Average Soil Burn Severity within basins in this study area

Hydrologic effects due to fire are addressed under Section 4.2, below.

1.4.3 Debris Flow Model Uncertainties

The USGS post wildfire debris flow regression model utilizes empirical data that relates slope, watershed relief, soil burn severity, and soils (a function of geology) to rainfall rates that do and do not trigger debris flows. This model can be used to solve for the spatially explicit rainfall rate that produces a 50% probability of debris flow in a watershed (Staley, 2017). According to the model results, thresholds range from 0.8 to greater than 1.6 in/hr at the 15-minute duration in the study area. However, there has not been extensive validation of the USGS debris flow model outside of southern California. Historic post wildfire debris flow event data from Big Sur suggest that regional empirical data for rainfall intensities capable of triggering post-fire debris flows are within the range predicted by the model.

Given that the National Oceanic and Atmospheric Administration's Atlas 14 precipitation frequency estimates indicate 1-year return interval rainfall intensities can exceed 1.7 in/hr for a 15- minute duration (0.4 in/15 min), it is unclear whether hillslopes may be climatologically adjusted to these rainfall intensities and whether it will require potentially higher rainfall intensities to trigger post-fire debris flows than the models suggest. Staley et al. (2020) found that post-fire debris flows are generally triggered by the 1- to 2-year recurrence interval storm event. Assuming this relationship holds for the CZU Lightning Complex, this suggests the rainfall rates might have to be as high as 1.4 to 2.0 in/hr (approximately 35-50 mm/hr) for a 15-minute duration (0.35 to 0.5 in/15 min).

Field observations and high-resolution topographic imagery indicate that debris flows have previously occurred within and downstream of the study area without the influence of wildfire. In portions of the watersheds much loose rock and soil materials were observed upslope of watercourse channels. Recent studies have shown that the presence of fresh, loose rock and soil materials high in burned watersheds (DiBiase and Lamb, 2020) are a strong predictor of post-fire debris flow initiation. In addition, the very low/unburned and low soil burn severity mapped within some of the burned basins may not accurately reflect on-the-ground conditions because canopy was not consumed. The combination of loose materials and possible higher soil burn intensities in some of the watersheds may not necessarily be reflected in the USGS modeling and calculated threshold rainfall rates. As such, there is considerable uncertainty regarding post wildfire debris flow hazard predictions for the study area.

2.0 HISTORY OF LANDSLIDING, FLOODING AND REVIEW OF AERIAL PHOTOGRAPHS

2.1 History of Landsliding and Flooding

Storm driven shallow landslides and debris flows are regularly triggered within the Santa Cruz Mountains during heavy rainfall seasons (Cooper and Clark, 1975; Ellen et al., 1997a and 1997b; Baum et al., 1999). Historically the Santa Cruz Mountains have experienced destructive landslide events, notably during the winters of 1981-1982 and 1997-1998. Many debris flows and shallow landslides were triggered within the vicinity of the study area during the January 1982 El Niño storm, including the Love Creek Landslide, located east of the burned area near Ben Lomond, which buried 9 homes and killed 10 people (Cotton and Cochrane, 1982; Ellen et al., 1997). These destructive regional landslide events led to significant research efforts into the causes of landslides in the area and how they could be better predicted and mitigated.

In contrast to runoff-initiated debris flow concerns within the first 2 to 5 years after wildfire, the effects of wildfire on shallow landslide activity in redwood forested terrain are poorly understood. Research in burned areas indicate a period of increased shallow landslide driven debris flow susceptibility between 2.2 and 10 years in forested areas of the Sierra Nevada (DeGraff et al., 2015) and 5 to 10 years after a fire in the Pacific Northwest (Wondzell and King, 2003). This increased susceptibility is thought to result from increases in soil moisture and attendant buildup of pore pressure that may persist for several years after wildfire because of decreased evapotranspiration (Helvey, 1980) and wildfire-induced tree and shrub mortality and the long-term decay of roots which may be accompanied by the reduction in apparent soil cohesion (DeGraff 1997, 2015). In contrast with the forests in the above regions, coast redwoods are self-sprouting and may not have the same level of long-term decay of roots following a fire.

Following the 1982 storms, several researchers established antecedent rainfall accumulations and storm rainfall conditions that produced widespread shallow landslides and debris flows. These studies showed that above 10 in. (254 mm) of antecedent rainfall and storm rainfall of greater than 0.2- 0.4 in. (5-10 mm) for some period, were responsible for widespread shallow landsliding. Recently, East et al. (2018) conducted research into the relationship between precipitation and suspended-sediment concentrations (SSC) on the San Lorenzo River. Their research found a relationship between antecedent precipitation accumulation above the generally accepted antecedent accumulation of 10 in. and subsequent intense storm events causing numerous landslides during the 2016/17 winter season. An evaluation of data from the Ben Lomond (BLO) RAWS weather station measured between 1998 and 2016, indicates total rainfall over 9.8 in. (250 mm) was measured 19 times. Furthermore, at the same station, a rainfall rate of 0.4 in/hr (10 mm/hr) occurred 255 times after an antecedent rainfall of 9.8 in. (Oakley, 2018). An annual average of 13 over threshold events after antecedent rainfall has occurred during this 19-year period.

It is unclear whether hillslopes in the study area will be sensitive to infiltration dominated shallow landsliding processes in the near term. Uncertainties include potentially limited infiltration due to decreased residence time of water on the surface due to hydrophobic and soil sealing conditions. Additionally, within the Redwood and Tan Oak vegetation communities subject to moderate and low burn severity, there exist unburned interlocking systems of shallow roots that may remain intact and healthy as the regrowth occurs during re-sprouting. However, as hydrophobic and soil sealing conditions reduce with time, infiltration may increase, and hillslopes underlain by existing landslides, over-steepened hillslopes adjacent to streams, and soils where shallow root systems are permanently damaged, may become sensitive to shallow landslide activity.

There has not been a significant wildfire of the scale and intensity of the CZU Lightning Complex within the study area within recorded history (Figure 3). The 2009 Lockheed Fire area, located outside of the study area, occupies about 9.0 percent of the western portion of the 2020 CZU fire area, and is only partially underlain by granitic bedrock that is fringed by sedimentary bedrock. Observations of post-fire runoff after the 2009 Lockheed fire were observed to be minimal (Loganbill, 2013); however, the geology and soils are somewhat different, and slopes are comparatively more gentle than the steeply sloping watersheds draining towards the Boulder Creek study area. Observations conducted during this evaluation indicate that many of the study area basins that drain towards developed areas along State Routes 9 and 236 contain significant areas of loose and weathered bedrock material that was observed perched on steep drainage headwall and sideslopes. Slopes in the study area are 3 to 4 times steeper than those in the western portion of the 2020 CZU fire area (Finnegan, 2017). It is reasonable to assume potentially adverse effects to shallow slope stability will be exacerbated for the next several winter seasons because of the 2020 CZU Lightning complex wildfire, particularly in the study area.

Additional information on the history of landsliding and research into storm driven landsliding in the Santa Cruz area is provided in Appendix A.

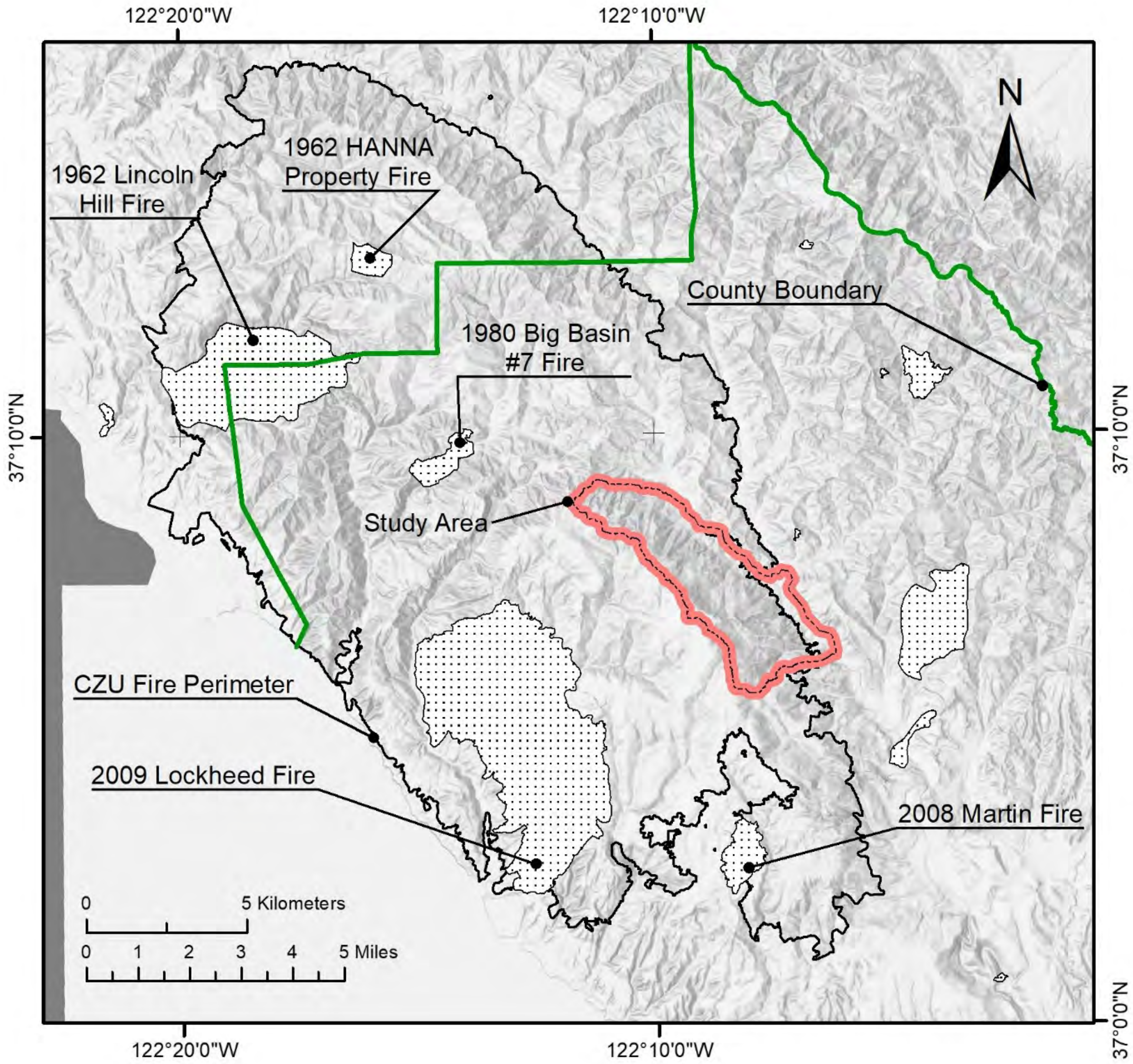

Figure 3. Regional Fire History in the CZU Burned area.

2.2 Aerial Photographic Review

CGS obtained a variety of aerial photographs from the University of California – Santa Barbara online air photo library that were sourced from San Mateo County, California Department of Forestry and Fire Protection, United Stated Department of Agriculture, California State Library, United States Geological Survey National Aerial Photography Program. Photo dates were 1941, 1948, 1956, 1963, 1982, 1987, 1993, and 1998 and had scales ranging from 1:20;000 to 1:40,000. Several of the photo sets reviewed were taken within months (i.e., 1956, 1993, 1998) or even days (1982) following major flooding and landslide events documented in the study area. Others (i.e., 1941, 1987) were taken up to a year and a half after major flooding and landslide events. The 1948 photo set, while not temporally proximal to a major flood, was relevant to the review of effects from the

1940 flood, considering the 1941 photo set contained only one photo that covered the northern half of the study area. Additionally, google earth imagery from 2002 to 2020 was reviewed online.

Review of the historic aerial photographs of the study area (tabulated in Appendix C) revealed evidence of active hillslope failure processes, in nearly every photo set, on isolated slopes throughout the study area, predominantly in response to documented storm events and especially precipitous rain seasons over the last 80 years. None of the aerial photographs reviewed showed any signs of past wildfires in the study area.

The most notable slope failures within the study area were debris slides in the steep headwalls and side slopes of the canyons that drain northeast to Boulder Creek and the San Lorenzo River, particularly evident in the years following the 1940, 1956, and 1982 floods. Debris slides in the uppermost reaches of these drainages were not observed to be related to obvious discrete downstream deposits, but usually seemed to correspond to downstream channel scour. A few hillslope erosional features appeared to be related to mid-slope and ridge-top road construction that has occurred at various times throughout the development history of the San Lorenzo/Boulder Creek Valleys.

Occurrences of flood-deposited sediment and debris on alluvial fans in 1982 where flood flows were intercepted by and conveyed through road networks were well-documented (The Storm of ’82, Appendix B). A Brookdale resident who witnessed the 1982 flooding provided the CGS team with photos taken around Clear Creek at Highway 9 during the recessional flows and aftermath of the flooding. Deposits of sand- to boulder-sized sediment, trees, and automobiles were photographed at the intersection of Clear Creek Road and Highway 9.

Despite the ground-based photographic evidence documenting the locations of several areas around Boulder Creek and Brookdale inundated by flood waters and debris (e.g., in 1940, 1956, 1982), visible evidence of effects on the alluvial fan landforms post-flooding were not observed in aerial photographs. It is worth noting that low resolution, small scale photographs and dense Redwood tree canopy likely precluded the direct observation of such surface effects, if they were present. Therefore, the extent of storm-related runoff is poorly defined and cannot be interpreted with confidence. Additional specific observations from the available aerial photographs are provided in Appendix C.

3.0 GEOMORPHIC SETTING

A series of steep canyons descend from the east flank of Ben Lomond Mountain toward the San Lorenzo River. From southeast to northwest, the canyons impacted by the CZU Fire include Clear Creek, Malosky Creek, Foreman Creek, Silver Creek, Peavine Creek, Jamison Creek, and several unnamed creeks. Bedrock in these source areas is largely composed of the granitic rocks of Ben Lomond Mountain. This rock is more resistant to erosion than the marine rocks in the region. Their relative resistant nature combined with the tectonic activity of the Ben Lomond fault and high regional uplift rates, produced the escarpment that hosts the drainages issuing onto alluvial fan landforms in the Boulder Creek study area. Although more resistant to erosion than softer marine rocks, the granitic bedrock in this region is both weathered and tectonically deformed and hosts widespread landsliding across a significant areal extent of the catchments. The weathered granite also provides a source for both fine-grained debris flow matrix material as well as larger cobbles and boulders. It is also notable that in these catchments much of the material conveyed to and deposited on the downstream alluvial fans is mobilized by episodic landsliding followed by entrainment of landslide debris during storm runoff.

Field observations indicate moderate accumulations of recent dry ravel in Clear Creek and several other drainages. In most cases, dry ravel accumulations were observed in steeply sloping ravines and swales below intensely fractured granitic bedrock outcrops have slope gradients of 100% (45°) or steeper. Most of the drainages were observed to contain alluvial channel deposits bordered by debris fans at tributary junctions as well as numerous landslide deposits. Extensive amounts of standing and downed variably burned trees and shrubs remain in many of the source canyon drainages. These observations suggest that under intense rainfall conditions:

- Moderate accumulations of dry ravel may contribute to debris flow and sediment generation during runoff.
- Existing landslides and debris fans impinging on channel networks may contribute to short- and long-term debris flow and sedimentation.
- Over steepened channel banks may locally fail during storm runoff events, providing additional sediment for entrainment and downstream deposition (numerous past stream-side landslide scars were observed).
- Trees and woody debris may be entrained in debris flows and floodwaters and have the potential to clog downstream culverts and bridges.

3.1 Alluvial Fan Geomorphic Mapping Approach

Discharge from the catchments has formed a series of alluvial fan landforms emanating eastward from mountain front with their distal portions interacting with the San Lorenzo River and Boulder Creek. As defined by the National Research Council in 1996, an alluvial fan is a sedimentary deposit located at a topographic break such as the base of a mountain front, escarpment, or valley side, that is composed of streamflow and/or debris flow sediments and which has the shape of a fan, either fully or partially extended (NRC, 1996). Alluvial fan flooding as defined by the NRC as:

> *a type of flood hazard that occurs only on alluvial fans. It is characterized by flow path uncertainty so great that this uncertainty cannot be set aside in realistic assessments of flood risk or in the reliable mitigation of the hazard. An alluvial fan flooding hazard is indicated by three related criteria: (a) flow path uncertainty below the hydrographic apex, (b) abrupt deposition and ensuing erosion of sediment as a stream or debris flow loses its competence to carry material eroded from a steeper, upstream source area, and (c) an environment where the combination of sediment availability, slope, and topography creates an ultrahazardous condition for which elevation on fill will not reliably mitigate the risk.*

Alluvial fans form progressively over time by divergent flow along distributary channels, forming a diagnostic “radial” fan-shaped landform. Distributary channels form by a process of avulsion where one channel becomes blocked by debris flow or debris laden runoff deposition, bank failure or capture, and future flows are diverted into a new flow path. This phenomenon is what leads to complex and unpredictable flow patterns on fan surfaces that can extend far beyond established channels and associated hazard zones designated based on riverine flood modeling. An active alluvial fan is the portion of the fan landform where the above processes have occurred in the recent geologic past and are possible in the future. As recommended by the NRC (1996), geomorphic assessment and mapping of the landform are necessary to identify the fan landform and which parts of the landform are active and inactive.

For assessment purposes CGS focused on the larger catchments having well defined channels leading to a fan apex; the location where the channel network joins the fan landform near the mountain front. The alluvial fans deposited by these larger drainages below the burn area are the result of deposition by a combination of streamflow and debris flow processes (e.g. Lancaster et al., 2015) and are typically termed composite fans.

Many of these composite fans have channels incised into them that allow flows to bypass the fan surface and enter the axial drainage. Differentiation between active and inactive alluvial surfaces can often be achieved by the close inspection of high-resolution topographic data (lidar) and its derivatives, review of historic aerial imagery, and identification of geomorphic indicators of weathering and erosion on surface expression of the landform. However, disturbance through development limits the efficacy of this method due to disturbance of the fan surface and the presence of unnatural preferential flow paths, such as roadways. To aid in this detailed assessment, we generated topographic maps with a contour interval of approximately 3 feet (1 meter). Inactive alluvial surfaces typically exhibit a deeply intrenched channel at the topographic apex and dissection of the surface where overland flows concentrate on the fan surface and cut small channels into the fan, roughening its topographic expression. On these inactive fans, only avulsions and multiple large flows depositing and filing the fan-head trench will cause the fan surface below that point to be occupied by water and/or sediment. In the study area these fans have been mapped with a continuous, deeply incised (10+ ft.) active channel (Qac) flanked by inactive fan surfaces (Qfi). Active alluvial fans are associated with smooth radial contours radiating from an incised or entrenched channel at or near the mountain range front. These smooth contours suggest active deposition and avulsions are occurring below a relatively fixed morphological (also called hydrographic) fan apex. These active fans have poorly-defined and shallow through-going active channels. Of special concern are fans with deeply incised (10+ ft) channels at their apex that shallow to incision depths of five feet or less at or below the fan apex. Active fan surfaces (Qfa), have likely hosted Holocene deposition (the current geologic epoch beginning 11,650 years ago), and if not influenced by cultural effects (i.e. grading, structures, etc.) will likely be areas of future deposition after intense storm events.

Many steep, unchannelized fans emanate from short steep canyons and were deposited dominantly by debris flow processes and are more appropriately termed debris fans. Many past debris flows that deposit on the alluvial and debris fans have been initially generated by shallow landslide failures in the source area rather than surficial erosion. Smaller fan landforms developed as a result of shallow landslide activity, attendant debris flow runout and deposition, are mapped ("Debris Fans" unit, Plate 1c) but are not considered as having the propensity for rapid concentration of surface runoff into ravines and channels, as in most cases either channels do not exist, or contributing areas are too small. If runoff and sediment generation were to occur, it appears that nuisance type flows would occur.

3.2 Preliminary Geomorphic Interpretation and Hazard Maps

CGS delineated potential impact areas as either high or moderate energy zones. In addition, we delineate unchannelized debris fans which are often associated with steeper fan slopes and shallow landslide sources. The preliminary mapping effort and the resulting preliminary hazard zones (Plate 1b, Appendix D) were based on field observations and the review of lidar acquired in 2020 (pre-CZU fire). High energy zones mostly correspond to the active channel geomorphic unit (Qac) and regions proximal to likely plugged channels. Moderate energy zones in the field area lie mostly in area flanking the active channel (Qac) which lie on the active alluvial fan surface (Qfa). The mapped moderate energy regions represent potential indirect overbank flows and avulsion paths. The geomorphic differentiation between active and inactive alluvial fans are portrayed on the hazard map because they represent different levels of background hazard associated with avulsions due to high magnitude flows. Active alluvial fan areas may experience deposition and impact after significant avulsion events at or above the hydrographic apex of a fan. Inactive alluvial fan areas are unlikely to be inundated unless multiple phases of deposition occur to backfill deeply incised channels followed by dramatic avulsions at or above the topographic apex. Channel crossings are depicted on the hazard map and show where the contributing area is at least 0.05 km^2. We have also included the FEMA 100- and 500-year riverine flood areas along the San Lorenzo River and Boulder Creek on our alluvial fan hazard map.

4.0 CHANNEL CONVEYANCE

4.1 Channel Constrictions

Channel constrictions ("choke points") or bends are significant drainage features that can lead to avulsions, reoccupation of inactive channels, and flow along unexpected paths, such as roadways, resulting in potential impacts to areas far beyond established channels. This assessment therefore focused on identifying and assessing potential constrictions based on the WERT assessment, more detailed mapping, past records related to previous flood events (for example 1982), and review of aerial imagery and lidar base maps and topographic contours developed from lidar. Through this effort we identified two primary categories of potential choke points, including 'natural channels' and 'crossing structures'.

Natural channel ‘choke points’ are areas within local channels that naturally constrict flow as a result of channel bends, large boulders, bedrock outcrops, trees growing within or immediately adjacent to the channel, or in areas where previous aggregation of alluvium has occurred. These natural choke points are susceptible to debris jams forming that can cause rapid aggradation and hydraulic jumps that can elevate the water surface, forcing it to leave its channel and occupy new areas within its flood plain or, worse, generate new flow paths in areas not previously occupied in historic time. Prediction of the location and magnitude of avulsion is not possible due to the boulder- and tree-lined nature of most of the channels investigated. Essentially, localized debris jams are unpredictable and can form at most any point during periods of high flow, causing the channel to avulse. Thus, our mapping focused on areas where, based on the indicators above, there appeared to be a higher likelihood of avulsion that could impact downstream properties.

The second type of choke point identified included man-made crossing structures, such as corrugated metal pipe (CMP) culverts, concrete box culverts, bridges and arch culverts, that appeared undersized to pass both increased runoff and debris under post-fire conditions. Crossings identified in the field at risk of becoming overtopped and where overtopping flows pose a risk to downstream life, property and infrastructure were mapped. Crossings where no significant impact would likely occur in the event of overtopping flows were not mapped.

Choke point locations are shown on the accompanying preliminary geomorphic interpretation and hazard maps, and information pertaining to each ’choke point’ is summarized and provided in the attached maps (Appendix D).

4.2 Hydrology/Hydraulics at Key Choke Points

To approximate the potential risks of a channel or crossing structure becoming overtopped during post-fire flows, we conducted basic hydrologic and hydraulic analyses to estimate flow capacity relative to the anticipated clearwater equivalent, post-fire bulked flow.

Clearwater equivalent post-fire bulked flow for each basin upstream of the choke points were estimated based on 2-year and 10-year storm events. The 2-year and 10-year storm events were selected and modelled for two reasons: the storms have a high probability of occurring over the next one to five years as the post-fire effects taper off and return to pre-fire conditions, and commonly used flood flow prediction methods have higher confidence with shorter recurrence interval events (2- to 10-year) compared to longer recurrence interval events (25- and 50-year) (Kinoshita et al.,2014).

Pre-fire peak flow estimates were produced for nine basins by taking the average between flow estimates obtained using the North Coast USGS regional regression equation (USGS StreamStats; Gotvald et al., 2012) and the flow-transfer method, as outlined in Waananen and Crippen (1977). The flow-transfer method estimates discharge at each site by scaling against gaged streamflow data obtained from a USGS gage along the San Lorenzo River at Big Trees Ca (USGS station #11160500). Flow data at the San Lorenzo River station range from the late 1930s to present (Figure 4). Annual flood frequency data were estimated for the San Lorenzo River station following procedures described in Flynn et al, 2006, using the USGS PeakFQ program, available at https://water.usgs.gov/software/PeakFQ/ (Figure 5).

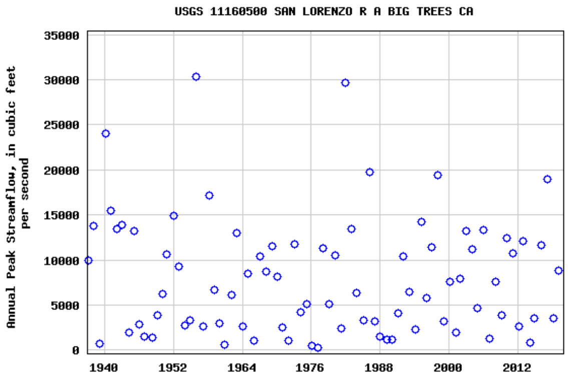

Figure 4. Peak Annual Discharge, San Lorenzo River

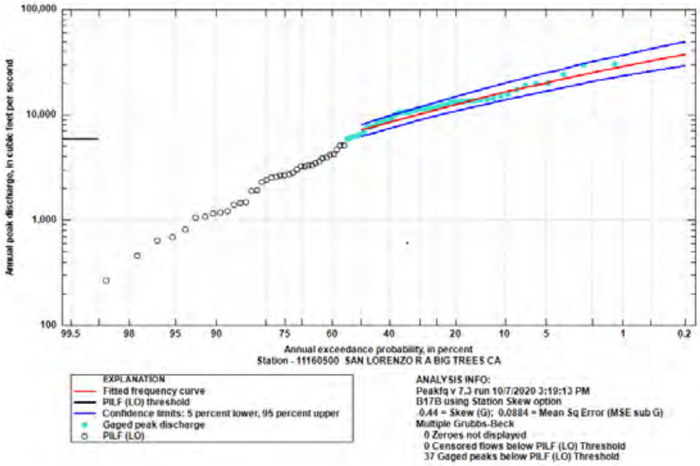

Figure 5. Annual Exceedance Probability, San Lorenzo River

Changes in post-fire peak flows were estimated using a flow modifier adapted from Foltz et al. (2009) to calculate post-fire clearwater flows. These flows were then bulked to account for entrained sediment and debris (Gusman, 2011). The predicted peak flow from 2- and 10-year rainfall events were then compared to flow frequencies derived for each modeled basin using the USGS Regional Regression Equations for the Northern Coast (Gotvald et al., 2012).

Results indicate that the 2- and 10-year storms can result in peak bulked flows that have flow multipliers between 1.3 to 1.8 and can result in flow responses equivalent to 3- to 4-year RI floods for the 2-year storm and 25- to 68-year RI floods for the 10-year storm. The largest change occurs within Clear Creek due to its larger percentage of moderate to high soil burn severity compared to the other basins.

Channel hydraulics were estimated using Manning's equation ($Q = (1.49/n)A(Rh^{2/3})S^{1/2}$) and the input parameter of average channel slope (S, ft/ft), Manning's roughness coefficient (n), cross-sectional area (A, ft^2), wetted perimeter (P), and hydraulic radius (A/P, ft). Crossing hydraulics were estimated assuming inlet-controlled conditions and applying the appropriate hydraulic nomograph depending on the inlet geometry and crossing type (circular CMP, arch culvert, or concrete box culvert).

Results of the hydrologic and hydraulic analyses are summarized in Table 3 (Appendix E). The natural channel choke points appear to have sufficient hydraulic capacity to convey the anticipated clearwater equivalent, post-fire bulked flows. However, as discussed previously, the potential for debris jams to form is difficult to anticipate and could reduce the hydraulic capacity of the channel, leading to overtopping flow conditions.

Most crossing structure choke points appear to have insufficient flow capacity to convey post-fire bulked flows. This is particularly the case for the 10-year storm event where five of the seven crossings evaluated appear undersized. The most problematic crossings, from north to south, include a box culvert that conveys flows from an unnamed watercourse under Jamison Creek Road, a box culvert that conveys Malosky Creek under State Route 9, and a constricted inlet where Clear Creek flows beneath the Brookdale lodge. It is assumed that all culverted crossings are at risk of plugging due to debris loading.

5.0 RESPONSE DECISION MATRIX

CGS assisted in the rapid development of a preliminary decision matrix based on four levels of response tiered to four different triggering rainfall events. The four response levels range in general risk from low to extreme and correspond to the following event characteristics:

> Level 1 ("lower risk"): Runoff is largely free of debris and stays within the current channel network. Debris flow potential is negligible. All flows stay within active channel as shown on Plate 1a (Appendix D).
>
> Level 2 ("moderate risk"): Runoff includes fine sediment (mud) and some debris. Debris flow potential at fan apex is low and moderate in first-order drainages. Avulsion potential moderate; All flows stay within high energy regions shown on Plate 1b (Appendix D).
>
> Level 3 ("higher risk"): Debris Flow potential is high for widespread small and moderate debris flows.; Avulsion potential high; Potential for flooding,

overtopping flows and channel avulsion is expected at channel choke points. Roads may be blocked and considered hazardous. Structures within designated hazard zones may be endangered. Flows may occupy high and moderate energy regions shown on Plate 1b (Appendix D).

Level 4 ("extreme risk"): Widespread abundant debris flows and flooding potential for avulsion and flooding is very high. Debris flows and sediment-laden floods are anticipated to move out of channels and over the channel banks. Roads are likely blocked and considered hazardous for travel. Structures, particularly those within the designated hazard areas, would be endangered. Flows may occupy high and moderate energy regions and active fan areas shown on Plate 1b (Appendix D).

The triggering precipitation thresholds for each response level were then prescribed and are presented in the following Figure 6. The Level 1/Level 2 precipitation threshold was developed by reviewing regional post wildfire debris flow events and associated precipitation data as discussed in the WERT report (CAL FIRE, 2020) as well as consultation with the U. S. Geological Survey's post-wildfire landslides team and the National Weather Service's San Francisco Bay/Monterey forecast office. The Level 2/Level 3 threshold represents the average between the 2-yr and 10-yr storm thresholds after taking into consideration the anticipated post-fire runoff and hydraulic capacity of local choke points. And the Level 3/Level 4 threshold is based on a 25-yr storm where widespread flooding, debris flows, and landsliding will likely occur. These thresholds are based on consultation with Santa Cruz County and on our understanding of field conditions present at the time of our assessment. It is recognized that field conditions will change if storm runoff and deposition occur, or if additional mitigation measures are implemented to increase conveyance or debris basin capacity. As conditions change over time, the thresholds may be adjusted to better match the new conditions.

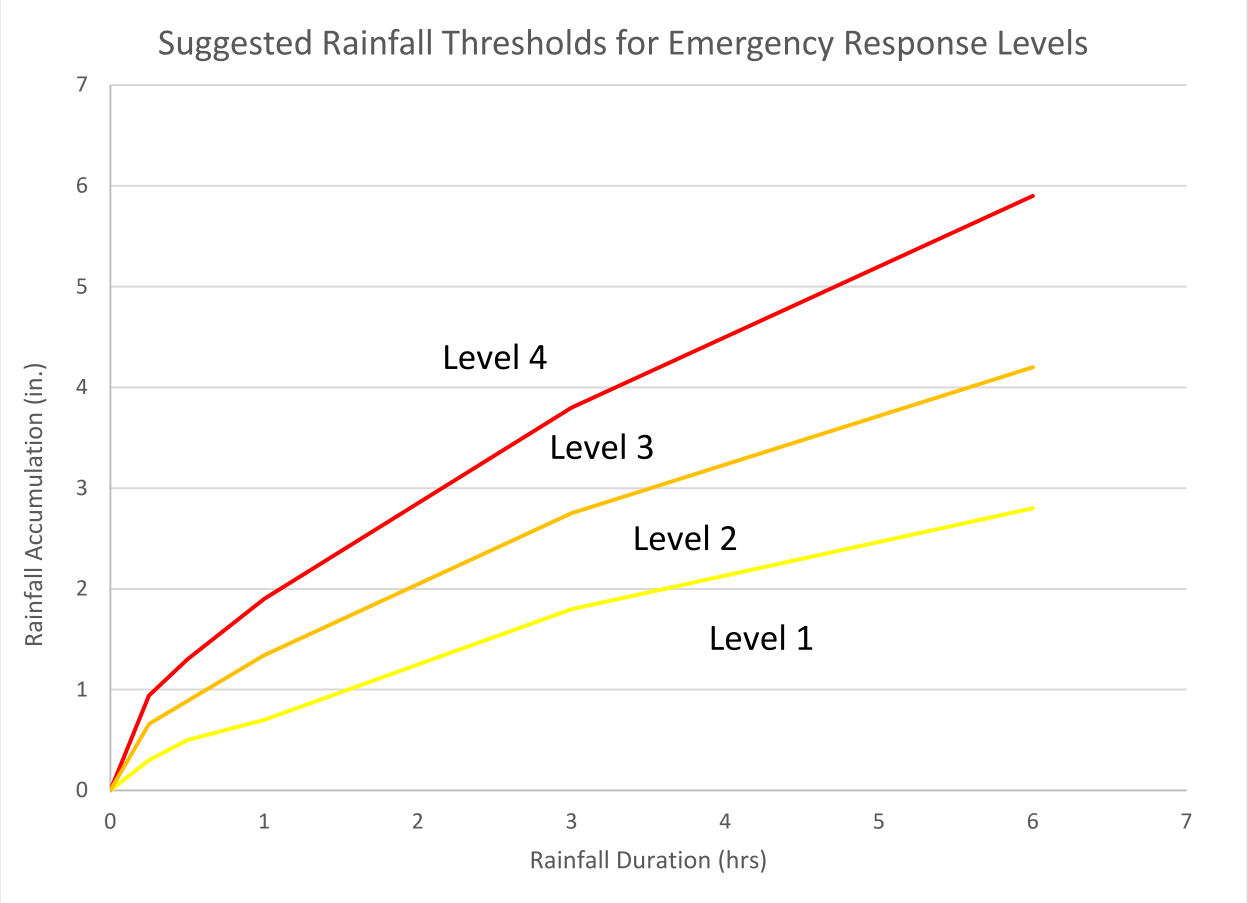

Figure 6. Precipitation depths and durations and emergency response levels.

The CGS team then prepared a preliminary matrix defining the rainfall event and corresponding debris flow magnitude and flooding potential to guide Santa Cruz County in the preparation of a decision matrix.

6.0 CONCLUSIONS

6.1 Fan Landforms and Activity

A combination of frequent strong ground shaking, tectonic uplift, fractured and sheared granitic and sedimentary basement rock that weathers to a loose regolith in steep catchments, with exposure to large storm events appear to be the major influences on alluvial fan and debris fan formation in the study area. Episodes of earthquake- and rainfall-induced landslides has likely led to loading of catchment channels. The entrainment of landslide debris during extreme storms has led to episodic deposition on fan surfaces where material loses momentum on flatter, less confined surfaces downgradient of the fan apices. While we do not know the age of the fans in the study area, based on fan morphology and the history of sediment laden flooding and debris slides that have occurred in the study area, we assume that episodic deposition has likely been occurring in Pleistocene and Holocene time.

6.2 Channel Capacity

Based on observations conducted during our evaluation it appears channel capacity at most locations evaluated should be adequate, but that debris jams can form causing channels to be overtopped and avulsion. Furthermore, several crossing structures were identified that pose a threat of becoming overtopped. The most problematic crossings, from north to south, include a box culvert that conveys flows from an unnamed watercourse under Jamison Creek Road, a box culvert that conveys Malosky Creek under State Route 9, low watercourse crossings in Harmon Creek, and a constricted inlet where Clear Creek flows beneath the Brookdale lodge. Based on our evaluation, predicted peak flow from 2- and 10-year rainfall events may produce sediment and debris deposition and overwhelm the channel conveyance capacity at these locations. It should be noted that all culverted crossings in the study area, despite their clearwater conveyance capacity, should be assumed at risk of plugging due to debris loading. Previous studies have shown that culvert crossing failures in forested environments are most likely to be caused by plugging via debris loading.

6.3 Geomorphic Interpretation and Hazard Maps

For assessment purposes, CGS differentiated alluvial fan landforms subject to channelized flow versus debris fans formed by shallow landslide activity. The preliminary mapping effort and the resulting preliminary hazard zones (Plate 1b) indicate high energy zones that correspond to the active channel geomorphic unit (Qac) and regions proximal to likely plugged and/or restricted channels. Moderate energy zones lie mostly in areas flanking the active channel (Qac) which lie on an active alluvial fan surface (Qfa). The mapped moderate energy regions represent potential indirect overbank flows and avulsion paths. Active and inactive alluvial fans are shown on the hazard map because they represent different levels of background hazard associated with avulsions due to high flows during extreme rainfall events.

The alluvial fan hazards zones are based on geomorphic interpretation of sub-meter hillshade imagery and field observations. The high energy zones (active channels) may experience flooding and possible avulsion during the predicted peak flow from 2- and 10-year rainfall events similar to what occurred in 1982. Moderate energy zones depict portions of active alluvial fan surfaces most prone to flooding and debris flow for storm events at or exceeding the predicted 10-year rainfall events. The active fan areas depicted may be occupied by flash flooding and debris flows during extreme rainfall events, at or above the Level 3 and 4 thresholds.

6.4 Response Matrix and Monitoring

CGS worked with the County of Santa Cruz to prepare a four-tiered response matrix for consideration by County of Santa Cruz emergency management personnel. It is anticipated that these emergency managers will use the information as part of their emergency management plans beginning the upcoming rain season.

This response matrix describes potential levels of flash flooding and debris flow risk given a frequent high-intensity rainfall event (Level 2) with low to moderate potential for debris flows and flooding where runoff includes sediment and some debris. Debris flow potential is low at fan apex, and moderate in first-order drainages. Avulsion potential is moderate, and flows are expected to stay within high energy regions shown on Plate 1b (Appendix D).

A less frequent event (Level 3) would include having a potential that is high for widespread small and moderate debris flows. Avulsion potential is high with a potential for flooding, overtopping flows and channel avulsion expected at channel choke points. Roads may be blocked and considered hazardous. Structures within designated hazard zones may be endangered. Flows may occupy high and moderate energy regions shown on Plate 1b (Appendix D).

The level 4 risk is considered extreme with widespread abundant debris flows and flooding. The potential for avulsion and flooding is very high. Debris flows and sediment-laden floods are anticipated to move out of channels and over the channel banks. Roads are likely blocked and considered hazardous for travel. Structures, particularly those within the designated hazard areas, would be endangered. Flows may occupy high and moderate energy regions and active fan areas shown on Plate 1b (Appendix D).

It should be noted that in this region there is a relative dearth of empirical data that would assist in better defining thresholds of runoff response. To assist in better defining thresholds in this region, CGS is working with the USGS and local university researchers to prepare a monitoring plan for the next several years after the 2020 CZU wildfire. The new observation data will help to establish watershed specific intensity-duration rainfall rates that do and do not trigger flash flooding and debris flows. As new monitoring data become available, we encourage the refinement of the response matrix when supported by new data.

6.5 Pre-existing Landslide Hazards

Some pre-existing landslide hazards are more sensitive to wildfire than others. These includes rock falls, shallow landslides and debris flows, and existing, relatively young landslide deposits that provide an abundance of weakened material underlying or bounding channels and ravines. Because of the loss of binding vegetation and root systems, and accumulation of loose soil, burn areas may pose an increased risk of landsliding over the background rate. As a result, rockfalls and shallow landslides may respond to much lower precipitation rates. Plate 1c shows where debris fan landforms exist within and down slope of small ravines and swales. These debris fan polygons may serve to understand where future debris flow impacts and deposition will occur.

Based on shallow landslide studies in the region a seasonal precipitation accumulation of 250 mm (10 inches) may be used as a rainfall precipitation accumulation total for consideration of increasing monitoring of potential shallow landslide and debris flow activity in the study area. Specifically, after the above antecedent rainfall conditions have been met, precipitation rates of greater than 5 to 10 mm/hr in the burn area should be monitored. Significant delays between early winter storm events and mid-winter intense storms may cause some drying of the soil mantle, thereby slightly lessening the shallow landslide risk. Conversely, a single long period storm with significant and intense rainfall rates may also increase the shallow landslide risk in this post-fire environment. The county may consider coordinating shallow landslide monitoring activities with researchers in the local USGS offices that monitor shallow landslide activity in the bay area.

6.6 Uncertainties

Models used in this evaluation help inform on the amounts of rainfall and conditions needed to trigger possible avulsion, flooding, and deposition from sediment laden floods and debris flows. However, many uncertainties exist that are not or cannot be predicted with current models. Because a wildfire has not burned in study area in recorded history, the uncertainty of the presence of loose sandy material, channel loading from numerous shallow landslides, and accumulation of large woody debris, are factors not accounted for in the modeling. The possibility of multiple events that result in the backfilling of entrenched channels can increase the potential for channel avulsion. For instance, a heavy winter that triggers sedimentation and landsliding and results in the loading of channels, followed by a high intensity storm could trigger hyperconcentrated and debris flows that contain woody debris, boulders, and cobbles. It should be clearly understood that a high degree of uncertainty exists as to where and when debris jams and avulsions may occur. We have provided information in this report using field observations, geomorphic interpretations, and current models to identify the most obvious areas of avulsion and resulting areas of impact.

7. GENERAL RECOMMENDATIONS

CGS encourages the consideration of the general recommendations developed in the 2020 CZU WERT report, as they are pertinent to the information utilized and hazards identified in this report.

7.1 Early Warning Systems

We strongly recommend that Santa Cruz County Department of Public Works, Santa Cruz County Office of Emergency Services (OES), the National Weather Service, CAL FIRE CZU San Mateo-Santa Cruz Unit, and other response agencies monitor rainfall intensities during and after storms, as well observe post-fire response following storm events. If the initial rainfall threshold is too conservative and little happens during storm events, data and observations should be used to adjust the threshold upward in a defensible manner.

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. Santa Cruz county should engage in a campaign or requesting residents and business to sign up for emergency alerts. In areas where cellular reception is poor or non-existent, methods should be developed to effectively contact residents. For example, installation of temporary mobile cellular towers should be considered. Early warning systems for the CZU Lightning Complex should take advantage of the following services:

National Weather Service Forecasting
Flash flood and debris flow warnings with practical lead times of several hours must come from a combination of weather forecasts, rainfall measurements of approaching storms, and knowledge of triggering thresholds. The following information is from the National Weather Service (NWS); they provide flash flood and post-fire debris flow "watch" and "warning" notifications for burned areas:

NWS – San Francisco Forecast Office: https://www.weather.gov/mtr/
NWS - Post-wildfire flash flood and debris flow guide
http://www.wrh.noaa.gov/lox/hydrology/files/DebrisFlowSurvivalGuide.pdf

CodeRED (Santa Cruz County)
The CodeRED notification system sends important messages to residents and businesses within Santa Cruz County in the event of emergency situations or critical community alerts. Examples of notifications include: evacuations, bio-terrorism alerts, missing person reports, and severe weather alerts.
https://public.coderedweb.com/CNE/en-US/218A80E36F49

SMC Alert (San Mateo County)
SMC ALERT is an alert notification system used to immediately contact people during urgent or emergency situations. Alerts can be set to send emergency and non-emergency text and voice messages to email accounts, cell phones, smartphones, tablets, and voice messages to landline phones. Emergency notification sign-up: https://hsd.smcsheriff.com/smcalert

Wireless Emergency Alerts (WEA)
WEA is an alert system originated by the NWS that can inform residents and businesses of flash flood warnings and other potential hazards. WEA alerts are emergency messages sent by authorized government alerting authorities through mobile carriers. Government partners include local and state public safety agencies, FEMA, the FCC, the Department of Homeland Security, and the National Weather Service. No signup is required, and alerts are automatically sent to enabled WEA-capable phones during an emergency. The emergency alert setting on WEA-capable phones must be turned on to enable this function.
https://www.weather.gov/wrn/wea

Emergency Alert System (EAS)
EAS is a national public warning system that may also be used by state and local authorities to delivery important emergency information, such as weather information, to targeted specific areas.

Integrated Public Alert and Warning System (IPAWS)

IPAWs is a FEMA-originated system that integrates federal, state, and local emergency warning systems (e.g., WEA, EAS) into a single interface.
https://www.fema.gov/integrated-public-alert-warning-system

7.2 Education for Residents and General Public

First and foremost, it is critical that residents heed evacuation warnings from local officials. In the absence of an official notice, residents should pay attention to evolving conditions around their homes.
Suzanne Perry, disaster scientist from the USGS, suggests the following:

- Be ready for debris flows for 2-5 years after a wildfire. Don’t worry about every storm, as it takes more intense rain (typically about ½ inch per hour – like being in a thunderstorm) on a recently burned slope to trigger a debris flow.
- Follow all evacuation orders. Debris flows can destroy everything in their path.
- Pay attention to official weather forecasts. The National Weather Service will issue a Flash Flood “Watch” or “Warning” for your area when rainfall is anticipated to be intense. Also – and this is important - the rain back in the mountains can be different than where you are. It’s the rain in the mountains that will start the debris flow.
- Don’t rely on what you’ve seen in past floods and debris flows. Debris flows can hit new areas or return to previous areas; they might be smaller - or larger - the next time. Whatever happened before, the next time could be different.
- If you must shelter in place, choose your spot in advance and stay alert. Find the highest point nearby (such as a 2nd story or roof) and be ready to get there with a moment’s notice. Listen and watch for rushing water, mud, unusual sounds. Survivors describe sounds of cracking, breaking, roaring, or a freight train.
- Never underestimate a debris flow. Unlike other landslides, debris flows can start in places they’ve never been before. They can leave stream channels and plow through neighborhoods. When a debris flow is small, people can control it with walls, K-rails, and sandbags. When a debris flow is big enough, nothing can stop it.
- Expect other flood dangers. Storms that can cause debris flows can also cause more common flooding dangers.
- Turn Around, Don’t Drown!® Never drive, walk, or bicycle through a flooded road or path. Even a few inches of water can hide currents that can sweep you away. Also, the water level can rise before you finish crossing.

For an easy to understand summary of what a debris flow is see Geology.com, What is a Debris Flow.

7.3 Rockfall, Slumping, Soil Slips and Small Landslides

Numerous shallow-seated landslides and rockfall hazards were identified during the 1982 storms (Appendix A), and on the sub-meter hillshade imagery (Tuckman, 2020). Many of these locations may be within the study area and may or may not be within the burned perimeter (for example cut slopes along the State Route 9 corridor). A fully comprehensive evaluation of rockfall hazard and small-scale landslide hazards was beyond the scope of this evaluation. DeGraff and Gallegos (2012) provide an overview of rockfall hazard following wildfire, along with suggested approaches for identifying these hazards. We strongly recommend more detailed analysis to further refine the identification of rockfall and small-scale hazard areas.

7.4 Road Drainage Systems, Storm Monitoring, and Storm Maintenance

The communities within and downstream of the burned area (including the study area) are serviced via a network of private and public roads and highways. Caltrans, Santa Cruz and San Mateo counties, and various cities and municipalities maintain numerous roads within and downstream of the burned area. Due to the fire impacts, increased flows on slopes and onto the road system and into storm drain systems can be expected. Loose and erodible soils that mantle the slopes could wash down, inundate, and plug these drainage systems. Flows could be diverted down roads and cause erosion and possible blockage, and/or loss of portions of the road infrastructure and structures along roads. We did not evaluate the potential for rockfall, sedimentation, flooding, or debris flow hazards at all roads or watercourse crossings along federal, state, county, municipal or private road corridors. 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.

7.5 Signage

Place temporary signage in areas of potential post-fire rockfall, debris flow, and flooding hazards. Place signage along roads, bridges, and other types of crossings identified at risk of flooding, rockfalls, and debris flows. We suggest responsible agencies consider installing gates, warning signs, or other measures to alert and keep people out of areas of identified risk.

7.6 Housing, Transitional, Temporary, New Permanent

During our evaluation we observed locations where housing structures were consumed and are also in areas of potential flooding and debris flows. 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. In addition to assessing the potential for increased flood hazards near watercourses, 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)? How about 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.

Aerial Photographs Reviewed (listed by date):

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Appendix A

Historical Overview of Landsliding in the Santa Cruz Area

Appendix A: Pre-Existing Landslide Hazards and Sensitivity to Wildfire

Introduction

CGS reviewed historical landslide events and storm rainfall accumulations and precipitation influencing those events in San Mateo and Santa Cruz counties to provide an understanding of storm-driven landslide hazard threat in the region of the CZU Lightning Complex Fire burn area. This literature review included published reports from Federal and State publications, peer-reviewed journals, local government planning reports and news reports. CGS first reviewed landslide occurrences in the burn area, and discussions of the geologic setting, topography and morphology unique to this portion of the Santa Cruz Mountains. Landslide types and hazards, including a review of the landslide events and

Landslide Types and Occurrences

The Santa Cruz Mountains have a long history of landslide events. Earth and debris flows, debris and rock slides, and rock falls have all occurred in the Santa Cruz Mountains in response to storm rainfall and earthquakes (Smith and Hart, 1982; Roberts and Barron, 1998). The watersheds draining into the Boulder Creek area host many landslides that create a pre-existing condition within the upland watersheds and range-front hillslopes. Some types of shallow landslides have increased susceptibility due to several fire related factors; these include shallow landslides, debris flows and rockfall, discussed later in this section. Fire related effects on deep seated landslide activity, such as rock slides and earth flows are less understood other than increased infiltration whether from loss of transpiration, significant rainfall quantities, or both, decreases slope stability in deep seated landslides. Earthquakes also influence slope stability both during/immediately after and in the subsequent rain seasons as a result of ground shaking which can affect marginally stable slopes and landslides, and open surficial fissures which allow more rainfall infiltration as evidenced following the 1989 Loma Prieta Earthquake (Cole, et al., 1998; Keefer, 2000).

Landslide Types

The Tertiary and Quaternary age formations in the burn area are typically marine sandstones and shales characterized by locally adverse bedding conditions conducive to landsliding. The soil mantle derived from the sedimentary rocks in the burn area may exhibit lower shear strengths and thus a greater potential to fail when excess precipitation infiltrates the soil. Additionally, Cretaceous age granitic rocks have been found to have undergone chemical weathering into decomposed granite and colluvium, an additional potential source of slope instability where they occur, for example, on Ben Lomond Mountain and slopes above Boulder Creek in the burn area (Cornerstone Earth Group, 2011).

As noted above, several types of landslides have been recorded in the Santa Cruz Mountains. These include:

- **Earth flow:** A slow-moving landslide resulting from cohesive, fine-grained (silt and clay) soil materials. Internal strength of these materials is low. When saturated, movement can cause a cumulative mass movement downslope. For example, the La Honda earth flow, a known landslide area, was reactivated during January 1998 during the historic precipitation accumulation that winter (Jayko, et al., 1998).

- **Debris flow:** These are typically fast-moving flows triggered by intense rainfall over a short period of time, often in soils that were already saturated from antecedent precipitation accumulation. Loose, non-cohesive soils, especially in post-fire areas with a significant reduction in soil-binding vegetation, may require less antecedent precipitation accumulation to trigger a debris flow.
- **Debris slide:** These can occur on steep slopes as a mass moving downslope that quickly breaks up into smaller blocks and falls or flows. Debris slides are typically comprised of coarse-grained and residual soils or decomposed and weathered bedrock. Precipitation from seasonal accumulation or even a single, intense storm may be enough to trigger a debris slide, moving at speeds ranging from meters per day to meters per minute. In colluvial hollows on hillslopes debris slides often mobilize and liquefy into destructive debris flows.
- **Rock slide:** These types of landslides commonly occur on steep slopes in competent rocks such as granitic bedrock or well-consolidated geologic formations where solid rock material collapses and may remain intact for a portion of the downslope movement. Excessive seasonal accumulation of rainfall may be a lead to rocks slides on the less competent failure plane that is experiencing high pore pressures.
- **Rock falls:** These occur where a mass of rock detaches from a steep slope by sliding, toppling or spreading, descending through the air by falling, bouncing or rolling. Intense precipitation, the reduction of stabilizing vegetation due to wildfire can trigger this type of landslide.

Some landslide types are more sensitive to wildfire than others. These includes rock falls, shallow landslides and debris flows, and existing, relatively young landslide deposits that provide an abundance of weakened material underlying or bounding channels and ravines. Because of the loss of binding vegetation and root systems, decreased transpiration, and accumulation of loose, burned debris, burn areas pose an increased risk of debris flows at much lower precipitation accumulation thresholds.

Landslide History

Historically the Santa Cruz Mountains have experienced destructive rainfall induced landslide events, notably during the winters of 1981-1982 and 1997-1998. Sometimes these regional events follow major earthquakes, such as the 1989 M 6.9 Loma Prieta earthquake. These destructive regional landslide events led to significant research efforts into the causes of landslides in the area and how they could be better predicted and mitigated. The most destructive type of landslide in the Santa Cruz Mountains has been debris flows, including fast-moving debris avalanches, because of their downslope speed (Smith and Hart, 1982). Our literature review has found that intense, sustained precipitation in the Santa Cruz Mountains is associated with regional-scale debris flow events (Smith and Hart, 1982; Wieczorek, 1987; Wilson and Jayco, 1997). These debris flows and debris avalanches have historically been the most damaging landslide type to life, property and infrastructure lifelines.

A significant portion of the study area is threatened with the potential for debris flows (USGS, 1997). The threat of landslides has been previously mapped across the study area in Santa Cruz and San Mateo Counties as part of the 1975 map by Copper-Clark and Associates as well as the United States Geological Survey in Open-File Report 97-745-C. Figure A1 shows reconnaissance-scale landslide hazard areas in Santa Cruz County (County of Santa Cruz LHMP, 2015).

Table A1 shows that regionally extensive debris flows that occurred during the 1981-1982 and 1997-1998 winter precipitation events caused the most damage and fatalities in San Mateo and Santa Cruz Counties historically recorded (Smith and Hart, 1982). The future threat of landslides to the public, property and structures is significant. The Santa Cruz County Local Hazard Mitigation Plan (County of Santa Cruz LHMP) summarizes the value of building and critical structure improvements exposed to landslide hazards. The County of Santa Cruz LHMP counts 27,990 parcels as exposed to landslide hazards, which includes over 21,000 structures, one school, three fire stations, and total improvements valued at $3,824,826,677 as of the 2009 assessment roll (County of Santa Cruz LHMP, 2015).

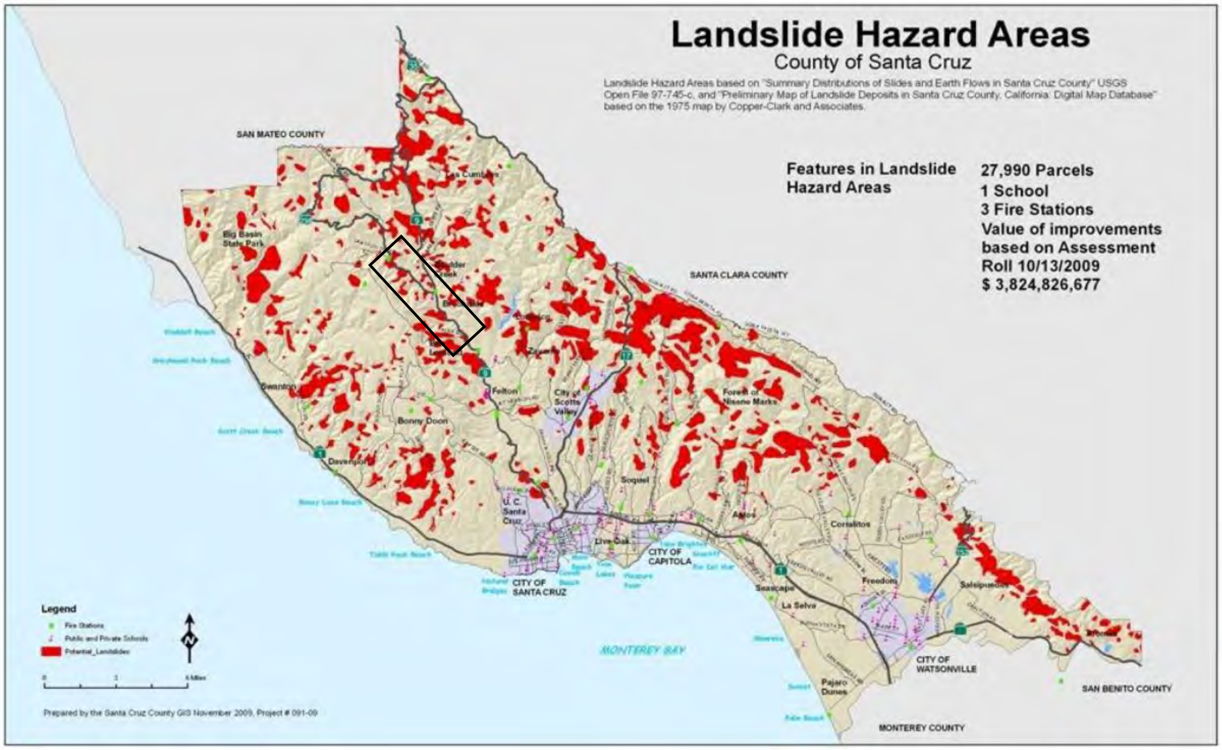

Figure A1. Santa Cruz County Landslide Hazard Areas within CGS Boulder Creek Study Area (copied from County of Santa Cruz LHMP, 2015).

Shallow Landslides and Debris Flows

Debris flow by failure of discrete slide masses on hillslopes have been documented in burn areas and generally involve soil and colluvial-mantled hillslopes. Shallow landslides result from an imbalance between: a) higher shear stress or driving forces imparted on the slope due to the soil mass, and b) gravity and the shear strength or resisting forces provided by internal friction, cohesion, and added strength from roots. This balance between driving and resisting forces is dependent on slope steepness, thickness and physical characteristics of the soil and the pore water pressure in the soil column atop an impedance layer that may form a slip surface.

In contrast to runoff-initiated debris flows that commonly occur within the first two to five years after wildfire, research in burned areas indicate a period of increased infiltration dominated shallow landslide driven debris flow susceptibility between 2.2 and 10 years in forested areas of the Sierra Nevada (DeGraff et al., 2015) and 5 to 10 years after a fire in the Pacific Northwest (Wondzell and King, 2003). This increased susceptibility is thought to result from increases in soil moisture and attendant buildup of pore pressure that may persist for several years after wildfire because of decreased evapotranspiration (Helvey, 1980) and wildfire-induced tree and shrub mortality and the long-term decay of roots which may be accompanied by the reduction in apparent soil cohesion (DeGraff 1997, 2015).

Precipitation Summary

The area of the CZU Lightning Complex Fire Burn area is characterized by a Mediterranean climate with hot, dry summers and cool, wet winters. The coastal location and orographic effects of the Santa Cruz Mountains results in significant precipitation. Accordingly, the Santa Cruz Mountains can have annual precipitation totals that significantly exceed the amounts in nearby inland valleys.

The winter months of December through March have been noted as the months of greatest risk of landslides (Cordeira, et al., 2019). The winter precipitation in the Coast Ranges typically results from North Pacific Ocean storms (Cordeira, et al., 2019). Winter 24-hour precipitation totals on the order of 3.94 to 5.90 in (100 to 150 mm) occur on a 2-year recurrence interval (Cordeira, et al., 2019).

El Niño conditions and atmospheric rivers may result in intense winter precipitation in California (Cordeira, et al., 2019; County of Santa Cruz LHMP, 2015; Smith and Hart, 1982; Oakley, et al., 2018; Young et al., 2017). Notable precipitation events in recent history include the January 1982 storm event and the January 1998 storm event. During the January 3 to January 5, 1982 storm event rainfall ranged from 11.8 in (300 mm) of accumulation to as much as 23.6 In (600 mm) (Smith and Hart, 1982), while the 1997-1998 winter set records for precipitation accumulation in the Santa Cruz area (National Weather Service, 2020). Active research continues regarding the classification of forecast storm intensities associated with atmospheric rivers (Oakley et al., 2016; Cordeira et al., 2019; Oakley et al., 2018; and Ralph et al., 2019).

Several factors influence the development of landslides; therefore, no single accumulation threshold will be able to predict with certainty a landslide at any location. Research in the Santa Cruz Mountains has been conducted on seasonal and storm-scale precipitation accumulation that lead to widespread landslide development. The sections below present our review of literature describing precipitation conditions.

Seasonal Precipitation Threshold Data

Studies of historic events in unburned areas demonstrate that a range of rainfall rates can produce destabilizing increases in pore water pressure after the soil has absorbed a threshold amount of moisture from preceding rainfalls (e.g., Campbell 1975; Reid 1997; Iverson 2000; Baum et al. 2010; Stock and Bellugi 2011). The soil moisture, or volumetric water content value at which water will flow out of a soil packet (column) at the rate at which it flows in, is often called field capacity and represents a likely precondition to the triggering of widespread landsliding from intense rainfall (Campbell 1975; Wilson and Wieczorek 1995; Baum et al. 2010). Rainfall that exceeds threshold intensity values should be more likely to cause landslides (e.g., Godt et al. 2006). There are several historic estimates of antecedent rainfall totals and rainfall intensity–duration thresholds that will trigger shallow landslides (Campbell 1975; Caine 1980; Cannon and Ellen 1985; Wieczorek 1987; Wilson and Jayko 1997; Casadei et al. 2003; Guzzetti et al. 2008; Stock and Bellugi 2011). Research from historic landslide events in the Santa Cruz

Mountains led to observations of rainfall seasonal accumulation (antecedent) rainfall that presents a widespread soil saturation scenario in the region.

Significant research has been conducted on storm event precipitation intensity rates and duration to cause landslides. Research by Cordeira et al. (2018) and Oakley et al. (2018) notes that 60 to 90 percent of extreme precipitation events that generate shallow landslides are associated with landfalling atmospheric rivers. It should be noted, however, that there are many variables and uncertainties that go into any identification of an intensity-duration threshold. Some of these can include local topography and geology, variability in timing and volume of antecedent rainfall, variability in storm intensity, and variability in storm meteorology (Cannon and Ellen, 1985; Oakley, et al., 2018; Cordeira, et al., 2019). Intense storms occur routinely in the Santa Cruz Mountains.

Recently, East et al. (2018) conducted research into the relationship between precipitation and suspended-sediment concentrations (SSC) on the San Lorenzo River. Their research found a relationship between antecedent precipitation accumulation above the generally accepted antecedent accumulation of 10 in (254 mm) and subsequent intense storm events causing numerous landslides during the 2016/17 winter season. The resulting storm runoff showed an order of magnitude increase in SSC in the San Lorenzo River with the conclusion that antecedent precipitation, with later intense storms, pre-conditioned the watershed for landslides and the resulting significant increase in sediment load.

Principal research on precipitation thresholds in the Santa Cruz Mountains are shown below:

- Cannon and Ellen, 1985: 10 in (254 mm) antecedent precipitation; established an intensity-duration curve ranging from 0.79 in/hr (20 mm/hr) average intensity for 3 hr duration (2.36 in, or 60 mm total storm accumulation) to 0.43 in/hr (11.5 mm/hr) average intensity for 10 hr duration (approx. 4.53 in (115 mm) total storm accumulation).
- Wieczorek, et al., 1987: 11.0 in (280 mm) antecedent precipitation;
- Cannon and Ellen, 1988: 10 in (254 mm) antecedent precipitation; based on 1982 storm, abundant debris flows after 18.5 hours of storm precipitation, of which 8 hours of precipitation intensities between 0.39 to 0.79 in/hr (10 to 20 mm/hr).
- Wieczorek and Sarmiento, 1988: 11.0 in (280 mm) antecedent precipitation; storm duration and intensity relationship established, with intensity-duration 3 hours at >0.20 in/hr (>5 mm/hr) as the most significant indicator of storms that will exhibit debris flows above 11.0 in (280 mm) antecedent precipitation threshold.
- Wilson and Jayco 1997: storm intensity duration varies by location.

Discussion

As discussed previously, the effects of wildfire on shallow landslide activity in forested terrain are not fully understood. Past and on-going research into debris flow precipitation accumulation thresholds suggest that in unburned conditions rainfall accumulations of over 10 in (254 mm) in seasonal accumulation, followed by mid-winter intense storms, resulted in debris flows across in the region. These events are frequent in this region. An evaluation of data from the Ben Lomond (BLO) RAWS station measured between 1998 and 2016, indicates total rainfall over approximately 10 in (250 mm) was measured 19 times. Furthermore, at the same station, a rainfall rate of 0.39 in/hr (10 mm/hr) occurred 255 times after an antecedent rainfall of approximately 10 in (250 mm) (Oakley, 2018). An annual average of 13 over threshold events after antecedent rainfall has occurred.

However, it is unclear whether hillslopes in the study area will be sensitive to infiltration dominated shallow or deep landsliding processes in the near term. Uncertainties include the widespread presence of hydrophobic soils developed on regolith in the granitic terrain that may inhibit percolation of stormwater for some period. Additionally, within the Redwood and Tan Oak vegetation communities subject to moderate and low burn severity, there exist unburned interlocking systems of shallow roots that may remain intact and healthy as the regrowth occurs during re-sprouting. However, as hydrophobic conditions break down, infiltration may increase, and hillslopes underlain by both existing landslides and soils where shallow root systems are permanently damaged, may become sensitive to shallow landslide activity. In addition, areas where canopy has been significantly damaged may experience more intense rainfall quantities/impact due to lack of interception. We suggest that seasonal precipitation accumulation of approximately 10 in (250 mm) be used as a seasonal rainfall precipitation accumulation total for consideration of increasing monitoring of potential shallow landslide and debris flow activity in the study area. Significant delays between early winter storm events and mid-winter intense storms may cause some drying of the soil mantle, thereby slightly lessening the landslide risk. December, and especially January and February, are key months for intense precipitation events from ARs. Our research indicates that precipitation rates of greater than >0.20 to 0.39 in/hr (5 to 10 mm/hr) in the burn area should be monitored.

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Appendix A (Continued)
Summary Tables of Landslide-generating Storm Events and Reported Landslide Locations

Table A1 lists major reported landslide events resulting from winter storms, while Table A2 lists specific point locations in and around the CZU Lightning Complex burn area. We present the year or, where appropriate, specific months or days when landslides occurred. Not all reports could be tied to specific locations in the CZU Lightning Complex Fire Burn area. The specific landslide occurrences we were able to locate can provide additional, site-specific input to antecedent precipitation conditions and local geology and morphology that lead to landslides in the CZU Lightning Complex Fire Burn area.

Table A1 also includes a summary of fatalities, property damage and value losses, where available. These values are presented in loss year dollars. Table A1 also includes the antecedent rainfall and storm event accumulations. Finally, Table A1 presents general comments about the landslide event and key references cited for each event. The comments provide anecdotal information or specifics of interest to the landslide event.

Available fatality and property loss data, including damage assessments, in loss year dollars, is presented in Table A1 and Table A2 for widespread storm event losses and individual location losses, respectively.

Table A1. Summary of damaging storm events in the CZU Lightning Complex Burn Area.

Year	Location	Impacts-Lives Lost	Impacts-Property Lost	Costs assoc. with damages	Annual Rainfall	Storm Rainfall	Comments	References
1905-1906	San Francisco Bay Area	--	--	--	--	--	Debris avalanches and debris flows.	Smith and Hart, 1982
1906-1907	San Francisco Bay Area	--	--	--	--	--	Debris avalanches and debris flows.	Smith and Hart, 1982
1949-1950	San Francisco Bay Area	--	--	--	--	--	Debris avalanches and debris flows.	Smith and Hart, 1982
1955-1956	San Francisco Bay Area	--	--	--	--	--	Debris avalanches and debris flows.	Smith and Hart, 1982
1957-1958	Mount Herman landslide (area of previously suspected older landslide).	--	--	--	Above normal precip year. Feb 19 was 150% of normal.[1]	Intense series of storms starting Jan 23 at antecedent 14.65" ending at 32.58" on Feb 20. 3.7" in 24 hrs (Jan 24).[1]	New movement extended from Kaiser Quarry to the bottom of Bean Creek blocking Conference Dr. One of the reasons for the Mount Herman Bypass. Quarry and a small earthquake may have contributed.	County of Santa Cruz Local Hazard Mitigation Plan 2015-2020 (Sept 2015)
1961-1962	San Francisco Bay Area	--	--	--	--	--	Debris avalanches and debris flows.	Smith and Hart, 1982

Year	Location	Impacts-Lives Lost	Impacts-Property Lost	Costs assoc. with damages	Annual Rainfall	Storm Rainfall	Comments	References
1962-1963	San Francisco Bay Area	--	--	--	--	--	Debris avalanches and debris flows.	Smith and Hart, 1982
1963-1964	San Francisco Bay Area	--	--	--	--	--	Debris avalanches and debris flows.	Smith and Hart, 1982
1967-1968	San Francisco Bay Area	--	--	--	--	--	Debris avalanches and debris flows.	Smith and Hart, 1982
1968-1969	San Mateo and Santa Cruz Counties	--	$1,245,518 (1969 dollars)	$1,195,500 public loss. $1,158,000 in litigation costs. $448,500 in county slide repair or stabilization (1969 dollars).	Normal annual accum. up to Jan 12 (13.13").[1]	10.45" received in storms between Jan 12 and Jan 31.[1]	Losses from several landslides in Santa Cruz Mountains.	https://pubs.usgs.gov/mf/0327/plate-1.pdf
1970	Santa Cruz County	--	--	--	9.96" antecedent accum. to Jan 7 (80% of normal)[1]	11.84" over 13 days (Jan 8-Jan 21)[1]	Digital compilation of mapped landslides for Santa Cruz County Planning Department	USGS OFR 98-792
1972-1973	San Mateo County	--	$1,284,000 private costs	$2,311,310 public costs (1973 dollars)	15.17" already received up to Nov 16.	10.68" accum. between Feb 2-14. 180% of	Significant early winter accumulation by Nov 15 (425% above normal).[1]	https://pubs.er.usgs.gov/publication/mf679

Year	Location	Impacts- Lives Lost	Impacts- Property Lost	Costs assoc. with damages	Annual Rainfall	Storm Rainfall	Comments	References
						normal as of Feb 14.[1]		
1974-1975	San Francisco Bay Area	--	--	--	--	--	Debris avalanches and debris flows.	Smith and Hart, 1982
1977-1978	San Francisco Bay Area	--	--	--	--	--	Debris avalanches and debris flows.	Smith and Hart, 1982
1982	Marin, San Mateo, Santa Cruz	Three fatalities from landslides in San Mateo County, 15 in Santa Cruz County. Regionally, landslides killed 19 and 5 missing/presumed dead.	100 homes destroyed, 35 mobile homes demolished, and 300 homes damaged in Santa Cruz County. 73,000 homes without electricity in SC County. Highways 9 and 152 closed due to landslides. Regionally, 231 destroyed homes, 6,295 damaged homes, 24 destroyed businesses, 1,014	$172.4 million in private property. $108.3 million in public property	13.16" as of Jan 1, almost equal to greatest recorded accumulation to date (1997-98 season).[1]	Up to 600 mm (23.6") for the storm event in the Ben Lomond area.[2] Precip. gage in Santa Cruz recorded 12.5" from 12/29/81-1/5/82.[1]	Block glide landslide and associated smaller debris avalanches caused ten of the known and presumed fatalities. Debris avalanches (*rapid debris flows)* were widespread. Other examples included rockfalls, soil falls, earth slumps, earth flows. Mean annual precip. in Ben Lomond is 46". In the 1981-82 winter 33.35" had already accumulated as of Jan. 1. 24-hr rainfall of 11.5" on Jan. 4 (a 100-yr recurrence).	California Geology (July 1982, p. 22). San Mateo County Local Hazard Mitigation Plan.

Year	Location	Impacts-Lives Lost	Impacts-Property Lost	Costs assoc. with damages	Annual Rainfall	Storm Rainfall	Comments	References
			damaged businesses					
Feb 12-21, 1986	--	13 deaths and 67 injuries across California	--	--	18.77" antecedent accumulation (93% of normal)[1]	10.99" over three days[1]	31.5" (800 mm) of rain during Feb 12-21 storm event.	SC County LHMP http://www.co.santa-cruz.ca.us/Portals/0/Local%20Hazard%20Mitigation%20Plan%202015-2020.pdf
Mar 24, 1991	Hwy 17 in Santa Cruz Mtns, SC County	--	Large rock fall closed Highway 17.	--	58% of normal antecedent precip. accumulation.[1]	2.09" of precip. in 24 hours.[1]		Larson, R.A. and Slosson, J.E., eds., 1997, Storm-induced Geologic Hazards: Case Histories from the 1992-1993 Winter Storms in Southern California and Arizona, Geological Society of America (11).

Year	Location	Impacts- Lives Lost	Impacts- Property Lost	Costs assoc. with damages	Annual Rainfall	Storm Rainfall	Comments	References
Feb 11, 1992	SW San Mateo County	--	--	--	Antecedent precip. was 64% of normal. 80 to 120% of the danger threshold	3.21" over preceding two days (2.59" on 2/11).[1]	Intense precipitation triggered numerous debris flows in a small rural area of southwestern San Mateo County.	Wilson, R.C., 1997, Operation of a landslide warning system during the California storm sequence of January and February 1993, Geological Society of America, Reviews in Engineering Geology, Volume XI.
Jan 1993	San Mateo and Santa Cruz Counties	--	Six roads closed in Santa Cruz County due to landslides.	--	--	Jan 1993 rainfall was over 200% of normal. 286 mm at SFO in Jan (242% of normal). Santa Cruz was 213% of normal for Jan.	Jan 13 and 15 was most intense. A number of small debris flows on roadways and natural slopes (for CZU, southern Santa Cruz Mtns in SC and SCl Counties (Ellen, S.D. written comm. 1993)).	Wilson 1997 - LS Warning System

Jan and Feb 1998	San Mateo (various cities, including La Honda and La Mar) and Santa Cruz Counties	San Mateo County: One fatality when a debris flow destroyed a house in Loma Mar. No recorded fatalities from ls in Santa Cruz County.	$7.24 million to private property. Landslide damage to private structures: 43 red-tagged and 3 yellow-tagged. FEMA declaration DR-1203.	San Mateo County: $55 million landslide costs. $1.2 million in FEMA/Federal grants. Santa Cruz County: $14.68 million in landslide costs. Eighty roads damaged.	143% of normal prior to Jan 11-12 storm event. 212% of normal as of Feb 8.[1] Greatest annual precipitation on recorded in Santa Cruz County.	Storm events: Jan 11-12 (3.2" on 1/12), Feb 2-3 (4.48" in two days), Feb 6-7 (4.1" over three days), Feb 19-21 (2.6" in three days).[1] Severe damage in the first week of Feb 1998 (over 200 mm recorded).	Hundreds of hillslope failures. Field recon data showed that most damage resulted in deep-seated landslide movement, likely due to prolonged winter precipitation compared to the intense storm event in 1982 which resulted in significant debris flows. La Honda slide began moving continuously starting Feb 11, accelerated after additional rain. Three houses were red-tagged as well as five other houses adjacent to it. San Mateo County began mitigation measures on the slide. 165 landslides: 51 debris flows, 40 earth and debris slides, 1 rockfall, 13 complex (slides and flows) and 60 of unknown type. Damaged areas included: Swanton, Boulder Creek, Eureka Canyon, Aptos and Corralitos. County of Santa Cruz LHMP noted that debris flows affected Hwy 9 and properties on Branciforte Rd. and Amesti Rd.	USGS MR-2325-D (1999) https://pubs.usgs.gov/mf/1999/mf-2325-d/mf2325d.pdf Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf

Year	Location	Impacts-Lives Lost	Impacts-Property Lost	Costs assoc. with damages	Annual Rainfall	Storm Rainfall	Comments	References
2005	--	--	--	--	Seasonal accumulation exceeded wettest year (1997) to date as of Dec 28.	7.61" over 15 days (12/28/04-1/12/05)	Brief mention of landslide damage in winter 2004-2005 in the Santa Cruz LHMP. No other details provided.	http://www.co.santa-cruz.ca.us/Portals/0/Local%20Hazard%20Mitigation%20Plan%202015-2020.pdf
Feb 17, 2005 - Jan 12, 2006	San Mateo County	Two (falling trees)	50 businesses damaged. Three homes damaged. FEMA declaration DR-1628	$100 million in regional damage (includes outside of San Mateo County).	3.52" antecedent rainfall[1]	14.92" in 26 days[1]	--	Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf
April 2006	San Mateo and Santa Cruz Counties	--	$6 million in County road damage. 83 separate damage sites around all of San Mateo County. Damaged fiber optic telephone lines in SM County. FEMA declaration DR-	$13 million across all of Santa Cruz County	34.85" as of 4/1/06 and 122% of normal. By April 22 accumulation was 41.73" and 140%	5.13" in six days between 3/28 and 4/4.[1]	Numerous debris flows. Damage at Devil's Slide (Hwy 1 closed for several months), SF Peninsula Coast, SC Mtns landslides. 83 damage sites across San Mateo County.	Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf

Year	Location	Impacts-Lives Lost	Impacts-Property Lost	Costs assoc. with damages	Annual Rainfall	Storm Rainfall	Comments	References
			1646 in San Mateo County.		of normal.[1]			
Dec 6, 2014	CA-84 East, between Old La Honda Rd, and Hwy 35/Skyline Blvd	--	--	--	140% of normal	3.41 inches over five days	Landslide led to a traffic alert for motorists on CA-84 East (only one lane open)	Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf
Jan and Feb 2016	Pacifica	--	Significant erosion led to dangers of bldg. collapse. Beach Blvd suffered notable infrastructure damage from erosion.	--	105% of normal antecedent precipitation[1]	12 inches in 30 days[1]	Coastal erosion (with associated landslides and sinkholes)	Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf

Year	Location	Impacts-Lives Lost	Impacts-Property Lost	Costs assoc. with damages	Annual Rainfall	Storm Rainfall	Comments	References
Feb 14, 2019	Santa Cruz Mountains	Bear Creek Rd had smaller mudslides blocking the roadway.	--	--	18.51" antecedent precipitation[1]	3.3" of precip in two days (2/13-14)[1]	Annual precipitation accumulation was close to normal prior to storm event.	https://sanfrancisco.cbslocal.com/2019/02/14/storms-bring-road-closures-mudslides-to-santa-cruz-mountains/

Notes:

1 - Most precipitation data gathered from Santa Cruz station data from NOWData - NOAA Online Weather Data (http://w2.weather.gov/climate/xmacis.php?wfo-mtr).

2 – California Geology, June 1982.

Table A2. Summary of identified rainfall induced landslide events in and around the CZU Lightning Complex Burn Area.

Year	Location	Fatalities	Property Lost	Costs assoc. with damages	Annual Rainfall	Storm Rainfall	Comments	References
1982	324 Blue Ridge Dr, Boulder Creek	2	--	--	See Table A1	See Table A1	Debris avalanche	California Geology July 1982
1982	365 West Lomond, Boulder Creek	1	--	--	See Table A1	See Table A1	Debris avalanche	California Geology July 1982
1982	Love Creek	10	--	--	See Table A1	See Table A1	"Gigantic" block glide with smaller debris flows	California Geology July 1982
1982	405 Farmer Street, Felton	1	--	--	See Table A1	See Table A1	Debris avalanche	California Geology July 1982
1982	4873 Branciforte Drive, Santa Cruz	1	--	--	See Table A1	See Table A1	Debris avalanche	California Geology July 1982
1982	Near 1242 Happy Valley Road, Santa Cruz	1	--	--	See Table A1	See Table A1	Debris avalanche	California Geology July 1982
1982	7307 Old San Jose	1	--	--	See Table A1	See Table A1	Debris avalanche	California Geology July 1982

	Rd, Soquel							
1982	4770 Porter Gulch Drive, Aptos	1	--	--	See Table A1	See Table A1	Debris avalanche	California Geology July 1982
Mar 24, 1991	Hwy 17 in Santa Cruz Mtns, SC County	--	Large rock fall closed Hwy 17	--	--	--	--	Santa Cruz County LHMP
Jan 1996	Recreation Drive, La Honda	--	A portion of lower Recreation Drive abandoned.	--	--	--	Deep-seated earth flow. Reactivated in 1998 and again in 2005.	Engineer's Report, County of San Mateo La Honda Landslide Assessment District, January 29, 2008, Assessment Report for Slope Stability Improvements Within the Landslide Area of Unincorporated La Honda Area of San Mateo County
Feb 26 and Mar 8, 1998	Scenic Drive, La Honda	--	Homes removed under Landslide Hazard Mitigation Act.	Property owners compensated 75% of assessed value (2003 dollars)	26.21" antecedent rainfall (greatest recorded to date)[1]	Two weeks of heavy rainfall early Feb 1998 (1/31 -> 2/8 was 200 mm of rainfall). (293 mm	Deep-seated earth flow. Few mm/day to about 20 cm/day 2/20 to 2/26. Landslide motion decreased after rainfall stopped and mitigation efforts by the County of San Mateo began. Reactivated after heavy rains in 2005.	USGS OFR 98-229. Engineer's Report, County of San Mateo La Honda Landslide Assessment District, January 29, 2008, Assessment Report for Slope Stability Improvements Within the Landslide Area of Unincorporated La Honda Area of San Mateo County

						over nine days[1])		
Feb 1998	380 and 400 Heartwood Hill, Boulder Creek	--	Property owners compensated $1,941,000, 75% of assessed value (2003 dollars).	--	See Event Summary for Jan and Feb 1998 precipitation.	See Event Summary for Jan and Feb 1998 precipitation.	Reactivated or accelerated landslide. Structures on these parcels were demolished by Corralitos GHAD. GHAD reimbursed for costs associated with demolishing structures on these parcels under the Landslide Hazard Mitigation Program.	County of Santa Cruz, 1999, Communication for Authorization to Proceed to Escrow for property acquisition at 380 and 400 Heartwood Hill Drive, Boulder Creek, CA, Heartwood Hill Geologic Hazard Abatement District, letter dated November 29, 1999.

Feb 1998	**Southern Santa Cruz County**. 1049, 1105, 1108, 1133, 1175 Amesti Rd. Corralitos ; 609 White Rd, Watsonville;226 Hayward Dr, Aptos; 19320 Hidden Springs Ln; 18704 Hwy 9	--	$1.9 million awarded from Landslide Hazard Mitigation Grant Program (HMGP) funds to Santa Cruz County for 10 residential properties affected by 1998 storms. 1049 Amesti: Home destroyed by "ground landslide".	SC County "FEMA awarded $1.9 million for 10 affected properties". FEMA Region IX: $22 million awarded statewide from LS damage (Federal 75% share). Total was $30 million. $151 million in housing assistance and emergency repairs and grants. Of this, $12.8 million for hazard mitigation projects.	See Event Summary for Jan and Feb 1998 precipitation.	See Event Summary for Jan and Feb 1998 precipitation.	Reactivated or accelerated landslide. Can rebuild with county permits. City may require engineering and geology reports for future building envelope. Red-tagged home destroyed and still on-site.	http://sccounty01.co.santa-cruz.ca.us/bds/board/19981124/042.pdf https://www.fema.gov/appeal/amesti-road
Feb 14, 2019	Santa Cruz Mtns	--	--	--	--	--	Bear Creek Rd had smaller mudslides blocking the roadway.	https://sanfrancisco.cbslocal.com/2019/02/14/storms-bring-road-closures-mudslides-to-santa-cruz-mountains/

Feb 1998	La Honda	--	Three houses at the head of the slide red-tagged. Five other houses on or adjacent to it. Residents of several homes on Esplanade Dr in Pacifica evacuated on Feb 22.	--	--	--	The main slide in La Honda began moving continuously since at least February 11, and movement accelerated after a period of rain. San Mateo County drilled three wells in a road crossing the slide and began pumping wells on February 26. The County dug plastic-lined trenches to facilitate drainage. The 30-foot cliff had retreated 10 feet to the rear edge of the homes over two weeks. Cliff erosion, soil fall, and rock falls slowed but water continued seeping.	Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf
Feb 2, 1998	San Mateo County (various cities)	17 fatalities in the region (includes other counties)	FEMA declaration DR-1203	$55 million damage to public and private property. $38 million in La Honda, Moss Beach, Pacifica, Daly City		Particularly severe damage during week of Feb 2.	Hundreds of hillslope failures. Most common types: earthflows and earth slumps, and pre-existing Polhemus landslide (earth slump) was reactivated.	Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf

				and Portola Valley.				
Dec 17, 2005 - Jan 12, 2006	San Mateo County	2 from falling trees	50 businesses damaged. Three homes nearly wiped out. FEMA declaration DR-1628	$100 million in regional damage (includes outside of SM County).	18.54	15.02		Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf
Mar 29, 2006 - Apr 1, 2006	San Mateo County		FEMA declaration DR-1646		34.85. 122% of normal	0.45		Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf
Apr 1, 2006	SF peninsula coast. Slide at Devil's Slide closed Hwy 1 for several months.		83 damage sites across SM County		See above. Well above normal and persistent rainfall.	0.45	Debris flow. Several debris flows during April.	Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf

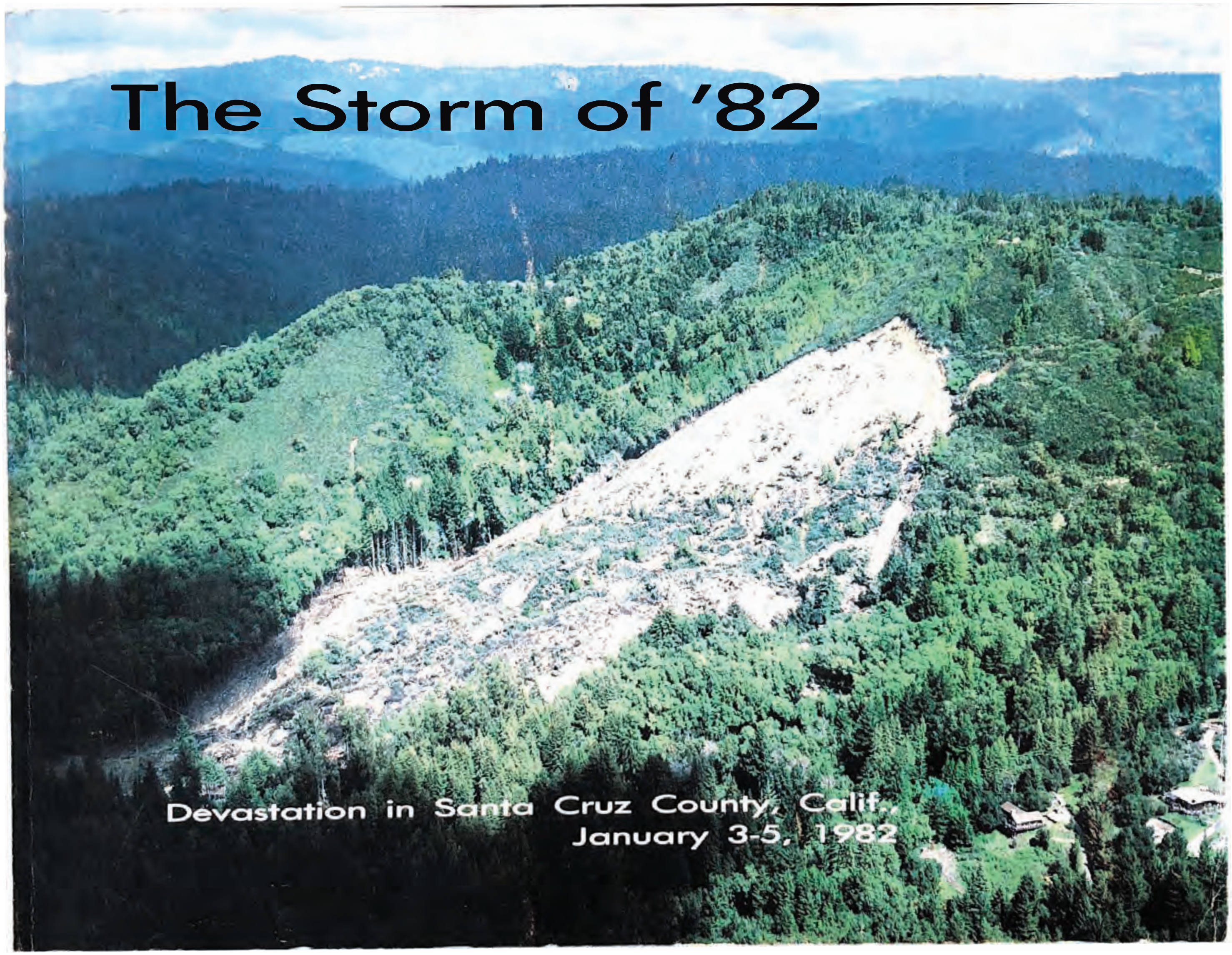
Apr 4, 2006	Santa Cruz Mtns		$6 million in County road damage.	$13 million	134% of normal. Heavy and persistent rainfall.	5.13	Debris flow.	Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf
Apr 22, 2006	Half Moon Bay. Coastal mountainous area near State Hwy 92 not accessible by vehicle.		Damaged fiber optic phone lines		140% of normal	Six days after last precipitation was measured.	Landslide. This appears to be days after the most recent storm event, and very late into seasonal accumulation.	Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf
Dec 2009	Pacifica		Evacuations in several apartments on Esplanade Ave. 30-foot land mass falling from the cliff.		Normal annual precipitation		Coastal erosion (with associated with landslides)	Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf
Dec 6, 2014	CA-84 East, between Old La Honda Rd, and				140% of normal	3.41 inches over five days	Landslide led to a traffic alert for motorists on CA-84 East (only one lane open)	Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-

	Hwy 35/Skyline Blvd							%20Volume%20I%20-%20Final%20APA.pdf
Jan and Feb 2016	Pacifica		Significant erosion led to dangers of bldg. collapse. Beach Blvd suffered notable infrastructure damage from erosion.		105%	12 inches in 30 days	Coastal erosion (with associated landslides and sinkholes)	Table 7-1. Landslide Events in San Mateo County. https://planning.smcgov.org/sites/planning.smcgov.org/files/documents/files/San%20Mateo%20HMP%20-%20Volume%20I%20-%20Final%20APA.pdf
Feb 14, 2019	Santa Cruz Mountains	--	--	--	--	--	Bear Creek Rd had smaller mudslides blocking the roadway.	https://sanfrancisco.cbslocal.com/2019/02/14/storms-bring-road-closures-mudslides-to-santa-cruz-mountains/

Appendix B

Excerpted Photographic Record of 1940, 1982 and 1986 Floods and Debris Flows.

The Storm of '82



Devastation in Santa Cruz County, Calif.,
January 3-5, 1982

COVER PHOTO: Aerial photograph made by Pete Amos shows the massive Love Creek slide which killed 10 persons on January 5, 1982.

Table of Contents

The Storm of '82

A Pictorial Essay of the
Destruction Inflicted by Torrential
Rainfall and Subsequent Floods
and Mudslides Which Ravaged
Santa Cruz County, Calif., on
January 3-5, 1982

First Printing, April 1982
Second Printing, May 1982
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Suddenly, The Storm Turned Deadly

IF SANTA CRUZ area residents were worried about another storm as they rang in 1982 with traditional toasts to health and happiness, it was only because rain threatened to soak Candlestick Park, where the San Francisco 49ers were to host the New York Giants in the NFL playoffs on January 3.

The National Weather Service forecast was for rain for that Sunday game, with a chance of rain on January 4.

The skies held for three quarters of that game before umbrellas began sprouting throughout the stadium.

The rain was constant through the night, and by morning it had become almost rhythmic. Rain gauges in Santa Cruz measured more than eight inches. Rising rivers and creeks, however, went fairly unnoticed as workers and students arose and headed out from their homes.

At 7:30 a.m., Felton Fire Chief John "Mac" McDonnell checked the San Lorenzo River. It had 15 to 20 feet to go before cresting.

As the morning wore on, talk of the 49er victory turned to the weather as the rain became so annoyingly loud it clamored for attention.

The county Communications Center in the basement of the County Center began receiving calls of minor sliding on a number of rural roads. Not unusual considering the strength of the storm overhead.

Shortly before 11 a.m. came the first hint of what was rapidly becoming a 100-year storm as a Santa Cruz Police officer reported the San Lorenzo River had left its banks and was creeping toward the County Center.

That first hint of trouble was quickly followed by more calls of flooding and sliding throughout the northern part of the county. By the end of the day, the log would show some 3,500 emergency calls answered.

Just before 1 p.m., Soquel firefighters were dispatched to a call that the Heart of Soquel mobile home park was flooding from the overflowing Soquel Creek.

All off-duty firefighters were called back to work to help downtown merchants there sandbag their storefronts just in case a repeat of the 1955 flood was ahead.

Before the night was over, a massive logjam upstream would detour Soquel Creek out of bounds and the worst fear of the merchants would be realized.

Flooding was reported elsewhere: the flats of Rio del Mar, the Lee and Market street areas near Branciforte and Carbonero creeks in Santa Cruz, and Felton Grove along the San Lorenzo River.

Evacuations began.

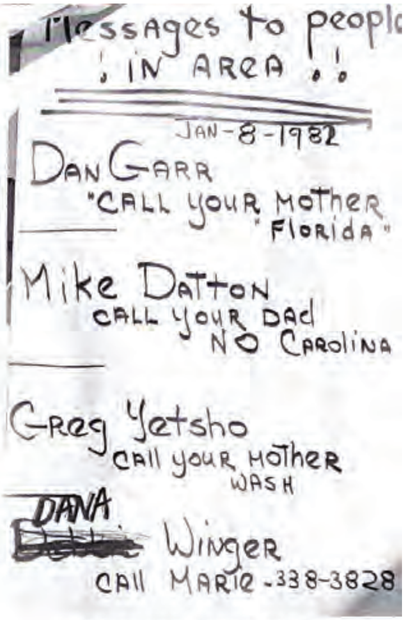
By nightfall, it was generally believed that Soquel and Aptos were sustaining the most damage and that the biggest threat would be the San Lorenzo overflowing when it passed through Santa Cruz at high tide.

Santa Cruz City emergency crews kept constant watch from the four bridges which span the river. Comparisons began to the 1955 flood which had inundated the entire downtown area.

Cranes were stationed on the bridges to keep the giant redwood and madrone logs from stacking up as they did in '55.

Shortly after 1 a.m., bystanders pointed to a crack on the Soquel Avenue Bridge. Workmen scrambled to their crane and got off the bridge a split-second before one lane of the span collapsed into the raging torrent.

In the early morning light, the sight of the broken bridge was stark testimony to the power of the storm.



Messages to peopl
! IN AREA !!

JAN-8-1982

DAN GARR
"CALL YOUR MOTHER
"FLORIDA"

Mike Datton
CALL YOUR DAD
NO CAROLINA

Greg Yetsho
CALL YOUR MOTHER
WASH

DANA
~~[illegible]~~ Winger
CALL MARIE - 338-3828

Message board at Ben Lomond Firehouse kept residents informed.

County disaster officials assembled early in the basement of the County Center and began putting together an assessment of damage.

A death list was begun. That list eventually would include the names of 17 persons known dead and five more missing and presumed dead.

By noon, that list showed eight persons known dead and two others missing.

But that was still some two hours before the first survivors of the Love Creek area of

CONTINUED

The Soquel Avenue Bridge was the raging San Lorenzo River's major victim in the city of Santa Cruz.

CONTINUED

Ben Lomond had made their way out to tell about what happened there.

Pounded by 19 inches of rain, a huge portion of the hillside had given way without warning, burying seven homes and claiming six lives.

As rescuers dug into the area, the death toll quickly mounted to 10 at Love Creek. Three months later, five of those bodies still had not been recovered because geologists had ruled the area too unstable to continue the digging.

Residents of 28 other homes in the Love Creek area were evacuated when a second slide began forming. By mid-March, geologists were predicting Love Creek never again could be inhabited.

By noon on January 5, the worst of the storm had been spent, but the problems continued.

The northern two-thirds of the county had been without power since 8:30 p.m. on January 4, and Pacific Gas & Electric Co. said it could take days to repair primary lines devastated in the mountains behind Soquel.

Thousands of East Santa Cruz residents were without telephone service because cross-town cables were snapped when the Soquel Avenue Bridge collapsed. It would be more than a week before full service could be restored.

Santa Cruz City Manager Richard Wilson announced the worst news, however. The city, he said, had only a 24-hour supply of water because the main transmission line from the Loch Lomond reservoir had been damaged.

Restaurants, laundromats and even hotels and motels were ordered closed. Residents were told to use water only for drinking and limited cooking.

Water supplies were cut off in the San Lorenzo Valley as well. The National Guard trucked in drinking water to Ben Lomond and Boulder Creek.

The Red Cross, Salvation Army and a number of churches set out to provide food, clothing and shelter for the more than 200 residents who were forced to flee their damaged homes.

Those living in remote areas of the San Lorenzo Valley found themselves cut off from civilization for days following the storm because of mudslides and washed-out roads. Many of those roads remained closed three months later.

County officials estimated dollar loss from the storm at more than $100 million, including $56 million to homes and private property.

President Ronald Reagan declared the county a disaster area and federal officials set up a center where residents could apply for money for food, temporary housing and for Small Business Administration loans to rebuild their homes.

But the biggest support for the disaster victims came from friends, neighbors and fellow residents of the Santa Cruz County community who helped them shovel mud and who raised and distributed hundreds of thousands of dollars for food and shelter.

Among the organizations participating in the relief effort have been the Red Cross, Salvation Army, Soquel Volunteer Relief Project, Food Nutrition Services, First Baptist Church of Boulder Creek, St. Andrews Relief Fund and the Santa Cruz County-Wide Citizens Disaster Relief Committee. That latter committee pledged to raise and distribute $1 million to storm victims. ☐

San Lorenzo Valley

•Ben Lomond/Love Creek

•Boulder Creek/Brookdale

•Felton

•Lompico/Zayante

Some kept lonely vigils while work crews searched for bodies of loved ones at Love Creek.

FIRST REPORTS from the San Lorenzo Valley were slow in coming. Boulder Creek, Brookdale, Ben Lomond, Felton and Lompico all were cut off from each other and from the rest of the county in the immediate aftermath of the storm.

County Supervisor Joe Cucchiara, who had made his way to the County Center, told disaster officials he would help assess "what's left of the The Valley."

Others described the scene as resembling a "war zone." Houses were destroyed. Highway 9 was covered with mud as hillsides came down all along its winding path. There was no power and no water service.

With more roads closed than open, many San Lorenzo Valley residents were waiting for the rain to finally stop so they could begin digging their way back to civilization.

Those forced to flee their damaged homes took refuge in shelters, where Red Cross and Salvation Army volunteers distributed blankets and clothing and served hot meals.

Volunteer firefighters who had been on the job round-the-clock since the storm began were continuing their grim task of digging for victims in slides and crumpled homes.

They would find 11 bodies, six of them in the Love Creek area of Ben Lomond, where a whole mountainside came down and buried seven homes.

Four more persons officially are listed as having perished in the Love Creek slide, but their bodies have not been recovered. Days after the storm, geologists ordered rescue crews out of the area, saying the slide was too unstable to continue digging.

An adjacent hillside also was found to be moving, forcing the evacuation of 28 homes. Three months after the storm, geologists still doubted the area could ever again be habitable. ☐

Boulder Creek/ Brookdale

Historic Brookdale Lodge's creek became a river during the storm, and when the waters receded it left a floor of mud.

Outside Brookdale Lodge the creek, which normally goes under Highway 9, became a scene of whitewater rapids.

A couple in a truck found an inundated Highway 9 impassable just south of Brookdale Lodge.

Irwin Way in Brookdale became a sea of mud and fallen trees where this PG&E employee worked to restore a power line.

Falling trees caused this destruction to a car and home at Hazel Road and Alpine Avenue in Boulder Creek.

This house and car along Hazel Road in Boulder Creek were crushed by falling trees during the January 3-5 storm.

At least four vehicles were buried in mud at this Highway 9 residence just north of Boulder Creek.

The Storm's Fatalities

The following is a list of confirmed deaths from the January 3-5 storm:

1. Joyce Smith, 33, 365 West Lomond St., Boulder Creek. Found at home January 4, 3:30 p.m. Died in mudslide.

2. Betsy Morgan, 40, 4873 Branciforte Drive, Santa Cruz. Found at home, January 4, 4:55 p.m. Died in mudslide.

3. Carole Seagrave, 34, 700 Cathedral Drive, Aptos. Found at home, January 4, 4 p.m. Died when tree fell through house.

4. Thomas L. Williams, 79, 405 Farmer St., Felton. Found at home, January 5, 7:20 a.m. Died in mudslide.

5. Paul Emerson Drake, 71, 4770 Porter Gulch Road, Soquel. Found at home, January 4, 8:45 p.m. Died in mudslide.

6. Kathleen Ann Cardoza, 25, 6011 Scotts Valley Drive, Scotts Valley. Found in San Lorenzo River in Henry Cowell Redwoods State Park, January 5, 3:10 p.m. Died when swept into creek at Lompico.

7. Jody A. Young, 53, Jody's Pet Motel, 7307 Old San Jose Road, Soquel. Found at home, January 5, 9:40 p.m. Died in mudslide.

8. John Michael Fuller, 36, 324 Blue Ridge Drive, Boulder Creek. Found at home, January 4, 11 p.m. Died in mudslide.

9. Daniel Bryant Young, 25, 310 Blue Ridge Drive, Boulder Creek. Found at 324 Blue Ridge Drive, January 4, 11 p.m.

10. Duncan Shaw Kidd, 27, 10900 Love Creek Road, Ben Lomond. Found at home, January 7, 3 p.m. Died in Love Creek slide.

11. Martin Keith Hallberg, 21, 1110 Lockhart Gulch Road, Scotts Valley. Found in Carbonero Creek, January 7, 7:53 a.m. Died when swept into creek.

12. Darrol Ray Anderson, 50, 202 Woodlander Place, Scotts Valley. Found on Stonewood Drive, Scotts Valley, January 8, 7:30 p.m. Died in tractor accident while clearing blocked roadway.

13. Lester Eugene Rumrill, 47, 10945 Woodland Drive, Ben Lomond. Found at home, January 9, 11:13 a.m. Died in Love Creek slide.

14. Yvonne Renee Blount, 32, 10945 Woodland Drive, Ben Lomond. Found at home January 9, 11:13 a.m. Died in Love Creek slide.

15. Patricia Ann Nelson, 42, 10971 Woodland Drive, Ben Lomond. Found at home, January 9, 1:30 p.m. Died in Love Creek slide.

16. John McCluskey, 32, 10985 Woodland Drive, Ben Lomond. Found at home, January 14, 12:30 a.m. Died in Love Creek slide.

17. Lynda McCluskey, 32, 10985 Woodland Drive, Ben Lomond. Found at home, January 14, 12:30 a.m. Died in Love Creek slide.

The following persons are missing and presumed dead: Body recoveries in Love Creek have been delayed because of closure of the area.

18. Trevor McCluskey, 7, 10985 Woodland Drive, Ben Lomond.

19. Kelly McCluskey, 5, 10985 Woodland Drive, Ben Lomond.

20. Mark Andrew Nelson, 21, 10971 Woodland Drive, Ben Lomond.

21. Hazel McGraw, 78, 10990 Woodland Drive, Ben Lomond.

22. Raymond Stanley, 41, near 1242 Happy Valley Road, Santa Cruz. Presumed trapped in house.

(FX100)BOULDER CREEK, Calif., Feb. 16--SEARCHING FOR OWNER--Rescue worker Leo Kuhnlein of the Boulder Creek Fire Department searches for Amy Ratnofsky, Sunday, who is believed to be buried inside the wreckage of her home. The house was smashed by a mudslide, Saturday, caused by the torrential rains of a severe winter storm. (AP Colorphoto)(pbl-11531-Please credit USA Today/Doug Menuez) 1986 (EDS: House is green, worker wears bright orange)

AP Cyan printer Magenta printer

darkest bar is printer color

AP

ACME NEWS PICTURES SANFRANCISCO BUREAU SF17417

WOMAN MAROONED IN TRAILER RESCUED IN CALIF. FLOOD

SANTA CRUZ, CALIF.---RESCUERS WITH BOAT AND BOOTS WERE NECESSARY TO RESCUE MRS A.P. BUCKLEY, WHO WAS MAROONED IN A TRAILER BY RISING WATERS OF SANLORENZO RIVER. (39) 2-28-40

Appendix C

Aerial Photograph Review

Date	Frame Number	Scale	Source	Location	Comments
3/23/1941	441	1:24,000	San Mateo Co.	1 mile east of Jamison and Boulder Creek confluence	Boulder Creek Elementary site on Harmon St fan is partially built with a clearing north of W Lomond St. N-S clearing and young orchard between Hwy 236 (Big Basin Way) and S. Redwood Drive. Water supply ponds visible upslope at sites of present-day SLV water co tanks. Despite the heavily forested drainages on the SW slopes above Boulder creek, the upper reaches of the Foreman Creek channel are visible through the canopy, especially at the northern bend just downstream of its tributary confluence. This suggests high flows that scoured the channel and its banks, and there were likely tree-toppling debris slides along the banks of the channel. Possible debris slide scars are visible along the southeastern and northwestern slopes of the drainage leading to the Acorn Fan. No deposits are noticeable at the Foreman Creek fan or along other creeks and fans to the north (Silver Creek, Peavine Creek, Acorn Fan, Logging Rd Fan). Acorn Fan road network apparently mostly in place at this point. These picrures were taken a little over a year after the 1940 flood. (See image at end of "Storm of '82")
5/5/1948	2-38	1:20000	CDF5	Boulder Brook Dr. @ Madrone Dr. near the mouth of Foreman Creek	New Powerline(?) corridor extending from the Hazel Ave/Redwood Ave area behind Boulder Ck Elementary, across the Harmon fan drainage, then up along ridges to Empire Grade. Brook lane developed between Big Basin Way and ridge east of Peavine Ck. Several fresh debris slide scars along the upper slopes of the Foreman Creek drainage near the ridge crest, likely resultant from the 1940 rains. Scour along upper Foreman Ck below debris slides is evident. Small debris slide near confluence of Foreman Ck and its unnamed southern tributary channel
5/5/1948	2-37	1:20000	CDF5	Headwaters of North Fork Clear Creek	Possible debris slide scar on northern slopes of North Fk Clear Creek, likely from 1940 storms. Clearing for Braemoor Dr development shows a prominent swale that drains to N. Fk Clear Creek. Present-day pond is has not been constructed. Development up Clear Ck is evident.
4/25/1948	4-11	1:20000	CDF5	1/4 mile north of Ben Lomond Conservation Camp along Empire Grade	Uppermost Foreman Ck debris slide scars visible.
8/13/1956	CJA-9r-49	1:20000	USDA	East of Conservation Camp in upper drainage above Logging Rd. fan.	Debris flow scars still visible in headwaters of Foreman Ck drainage, but no new features observed. Development (grading?) along Acorn Dr. south of Big Basin Way.

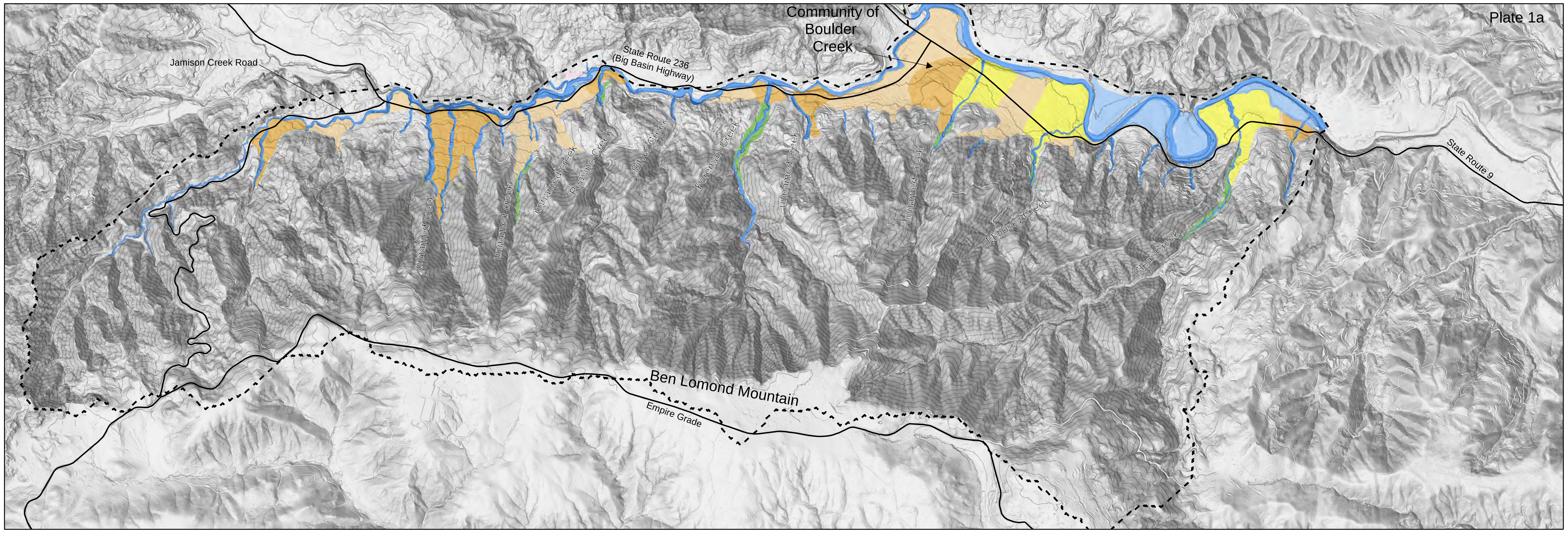
Date	Frame Number	Scale	Source	Location	Comments
8/13/1956	CJA-9r-50	1:20000	USDA	Peavine Ck headwaters	Braemoor Dr. development begun, pond is dammed and partially filled.
6/5/1956	CJA-5r-42	1:20000	USDA	~1/2 mile due west of Brookdale lodge	New clearing downslope of orchard south of N Fk Clear Ck/S Fk Clear Ck with downslope erosion gullies extending nearly to Clear Ck. Soil exposed at N Fk/S Fk confluence, possibly from development, but could be storm flow scour.
6/5/1956	CJA-5r-43	1:20000	USDA	Hwy 9 & Lomond St in Boulder Creek	San Lorenzo River appears farily sediment choked , particularly near Brookdale
6/4/1963	3-12	1:20000	CAS-SCR	~1/2 mile due west of Brookdale lodge	New disturbance north of Clear Ck, ~1/2 mile west of San Lorenzo meander in Brookdale. No present-day dev't there, so possibly a timber harvest. Further dev't SE of N Fk/S Fk Clear Ck confluence. No obvious slide features.
6/4/1963	3-13	1:20000	CAS-SCR	Highland Dr. in Boulder Creek	Expansion of SLV water supply ponds. No slide features evident
6/27/1963	1-64	1:20000	CAS-SCR	1/2 mile due west of N. Fk Clear Ck headwaters	Continued dev't of Braemoor Dr. neighborhood and filling of pond above Clear Ck. No new slide features evident
6/27/1963	1-65	1:20000	CAS-SCR	Ridge nose b/t Peavine Ck and Foreman Ck drainages, ~1/4 mile NE of Empire Grade	New road network on Logging Rd fan. Distinct debris slide in upper portion of Logging Rd fan drainage with apparent deposit immediately below. Minor channel scour down near topographic apex of Logging Rd. fan. New Hillside Way development up eastern side of Peavine Ck drainage.
6/27/1963	1-66	1:20000	CAS-SCR	Left side of Acorn fan	No new slide features evident.
1/8/1982	5-12	1:20000	USGS-JSC	Peavine Ck/Boulder Ck confluence	Deep(?) seated rotational slump north of Jamison Creek near tight switchback in Jamison Ck Rd. General Remark for all 1982 photos: Photos taken with low sun angle not conducive to channel illumination in steep-walled drainages of the study area
1/8/1982	5-11	1:20000	USGS-JSC	Middle of Foreman Ck drainage	No obvious hillslope failures
1/8/1982	5-10	1:20000	USGS-JSC	Empire Grade b/t Clear Ck headwaters and Alba Rd	Debris slide in uppermost Foreman Ck drainage due east of Braemoor neighborhood (along Empire Grade). Treeless slopes below ridge road along Northwesternmost Clear Ck headwaters exhibit scoured swales immediately downslope of road.
1/8/1982	6-11	1:20000	USGS-JSC	Bear Ck Rd @ Hwy 9	most channels obscured by shade, no deposits obvious

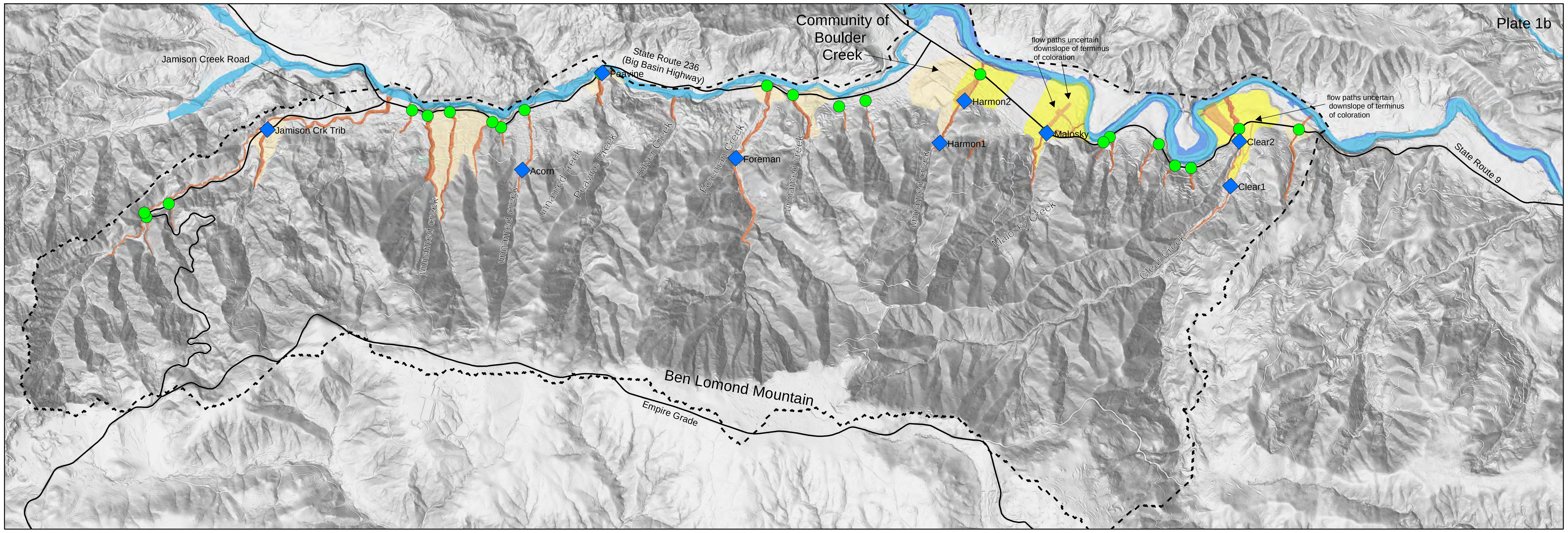
Date	Frame Number	Scale	Source	Location	Comments
1/8/1982	6-10	1:20000	USGS-JSC	Hwy 9 b/t Malosky & Clear Ck	Northern slopes of Malosky Ck drainage exhibit bare soil patches, indicative of potential debris slides. Upperslope swales along the northern slopes of N Fk Clear Creek shows signs of scour.
1/8/1982	6-9	1:20000	USGS-JSC	Marshall Ck @ Hubbard Gulch Rd	Probably the best angle for the Malosky Ck and Clear Ck debris slides. Lower deposit area of Love Creek slide visible in far right of image
7/2/1987	518-25	1:40000	NAPP	San Lorenzo River & Brown Gables Rd	Freshly scoured channel along the upper reaches of the drainage above the Harmon Fan
7/2/1987	518-26	1:40000	NAPP	~3/4 mile north of Fritch Ck/Love Ck confluence	Scour along Clear Ck downstream of N Fk/S Fk confluence.
7/2/1987	518-102	1:40000	NAPP	Boulder Ck Golf & Country Club	No obvious new slope failures
7/2/1987	518-103	1:40000	NAPP	Peavine Ck headwaters	Foreman Ck headwaters debris slide from 1982 photo 5-10 is very prominent in false color
6/11/1993	6354-33	1:40000	NAPP-2C	Boulder Creek Golf & Country Club	No obvious new slope failures
6/11/1993	6354-35	1:40000	NAPP-2C	Headwaters of Deadman Gulch a mile west of Empire Grade	No obvious slope failures. Treeless slopes and previously scoured swales in Northwesternmost Clear Ck headwaters appear to have stabilized.
6/14/1993	6355-10	1:40000	NAPP-2C	San Lorenzo River @ Marshall Creek	No obvious new slope failures
8/27/1998	10531-171	1:40000	NAPP-3C	Boulder Creek Golf & Country Club	Active channel draining to Logging Rd Fan exhibits scour upslope and past topographic apex. Exposed soil (channel scour? Debris slide deposits?) along Foreman Ck upstream of Boulder Brook Dr. development.
8/29/1998	10532-86	1:40000	NAPP-3C	Headwaters of Deadman Gulch a mile west of Empire Grade	Fresh scour along swales in Northwesternmost Clear Ck headwaters downslope of ridge road.

Date	Frame Number	Scale	Source	Location	Comments
3/16/2017	N/A	N/A	Google Earth	Coverage of Entire Study Area	Northern slopes of Malosky Creek and North Fk Clear Creek have some areas near the ridge that are vegetated with brushy and lacking tall conifers and hardwoods. The slopes beneath (to the south) the powerline corridor and associated ridge road experienced new erosion along existing debris slide tracks and gullies that existed prior to the 2016/17 winter season. No obvious deposits were observed downslope, either due to being obscured by the forest canopy or because the eroded material was flushed out of the drainages in high flows. The southern access road to the pad for the large San Lorenzo Valley water tank (upslope of Boulder Brook Drive off Hwy 236) experienced a fill failure likely associated with a moderately seated composite landslide that toes out toward the unnamed creek along Paone Drive. This feature first appeared after the 2016/17 storm season.

Appendix D

Geomorphic Hazard Maps





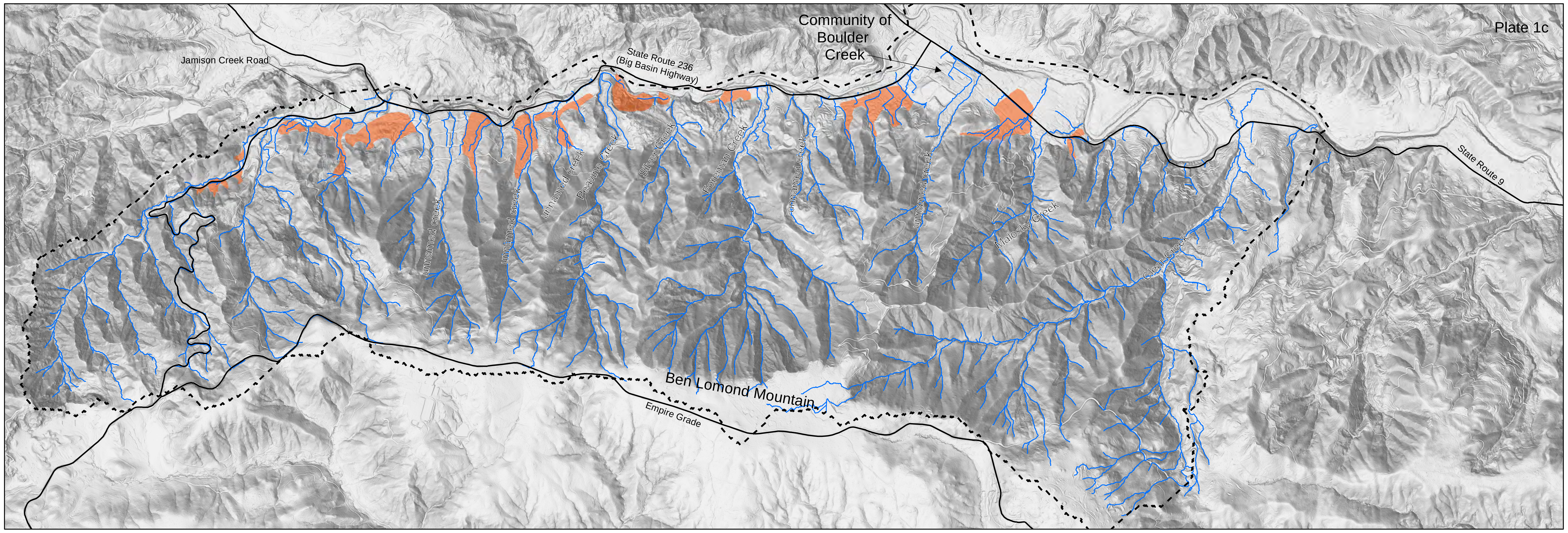


Plate 1: Geomorphic Interpretation and Hazard Maps

These maps were completed under Cal OES Mission Task 2020--SOC--42611 by the California Geological Survey, and accompany the report titled "Boulder Creek Post-WERT Study". Map frame 1a depicts interpretation of geomorphic surfaces of landforms in the project area. Map frame 1b depicts potential hazard areas on channelized alluvial fans due to post wildfire runoff, including debris flows and flooding, based on geomorphic mapping and field observations of potential choke points. The high and moderate energy zones on map 1b are related to risk levels discussed in Section 5 and Figure 5 of the project report. The active fan areas in map frame 1b depict areas that may be inundated during risk level 3 and 4 events, as discussed in Section 5. Inundation hazards on frame 1b also depict flow path terminations that are due to the limitations of this geomorphic assessment approach. Flow paths below these terminations may include any area down gradient. Map frame 1c depicts debris fan areas underlain by coalescing debris flow deposits resulting from landslides on nearby hillslopes, swales, and ravines.
Mapping effort utilized 0.6-meter resolution lidar collected in 2020 (bare earth model).

Geomorphic Surface Map Legend (1a):

🟦 Qac: Active channel areas, mapped up to and including risers

🟦 Qtr: Terraces deposited along axial river

🟩 Qtf: Terraces deposited along channels within alluvial fan and along upland channel

🟨 Qfa: Active fan surfaces below hydrologic apex that have likely been Holocene active

🟧 Qf: Undifferentiated alluvial and debris fan surfaces in low-sloping areas (below ~30%)

🟧 Qfi: Inactive fan surfaces with latest deposition likely pre-Holocene

▭ Study Area

— 20 meter contours

Runoff Inundation Hazard Map Legend (1b):

🟥 High Energy: Regions likely to be occupied by high energy flows (concentrated channel flow)

🟧 Moderate Energy: Regions likely to be occupied by moderate energy flows (overbank and thinner flows)

🟨 Active Fan: Areas of alluvial fan with possible inundation after significant avulsion events at or above hydrologic apex of fan

🟨 Inactive Fan: Areas of alluvial fan unlikely to be inundated unless dramatic avulsions occur due to exceptional blockage and/or above the hydrologic apex

◆ Choke Points

● Large Channel Crossings: Points where channels with drainages areas >0.05km^2 cross major highways and roads

FEMA Flood Zones:

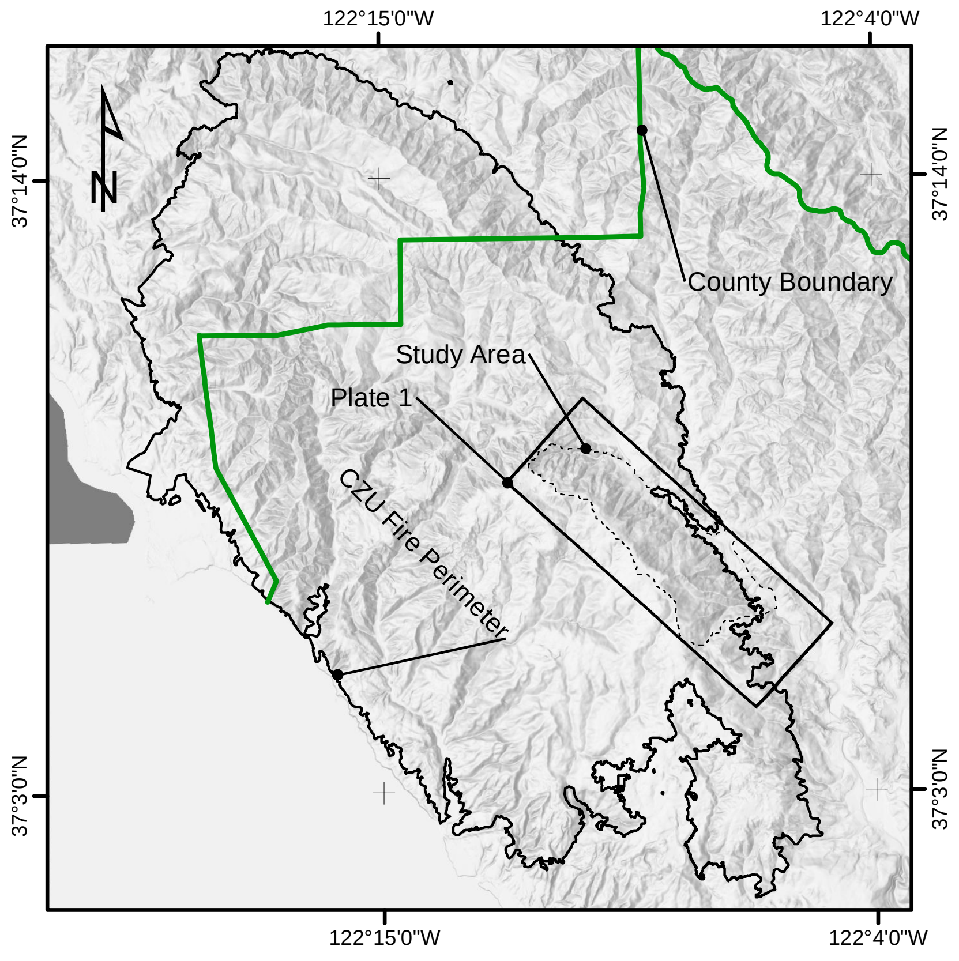
🟦 100-IC, A, and AE: 100-year flood area

🟦 X500: 500-year flood area

Debris Fan Map Legend (1c):

🟧 Debris Fans: Unchannelized fan deposits derived from debris flows and shallow landslides

— Channels with contributing area greater than 0.01km^2



0 0.5 1 2 Kilometers

0 0.25 0.5 1 Miles

Scale: 1:19,000

Appendix E

Table 3. Results of the hydrologic and hydraulic analyses.

Basin	Average pre-fire Clearwater flow		Average post-fire, bulked flood flow				Choke Point Hydraulics														
							Natural Channel					Crossing Structure									
	Q2-yr RI (cfs)	Q10-yr (cfs)	Q2-yr (cfs)		Q10-yr (cfs)		Channel Gradient (feet/ft)	Manning's #, n	Cross-sectional area (ft^2)	Hydraulic Radius (ft^2/ft)	Channel capacity at bankfull stage (cfs)	Structure Type	Max. clearwater flow, HW/D = 1 (cfs)	Qba 2-yr (cfs)		Qba - 10yr (cfs)		Qba 2-yr (cfs)		Qba - 10yr (cfs)	
														Ave. Pre-fire Flood Flow		Ave. Pre-fire Flood Flow		Ave. Bulked, Post-fire Flood Flow		Ave. Bulked, Post-fire Flood Flow	
	Ave. Pre-fire Flood Flow	Ave. Pre-fire Flood Flow	Ave. Bulked, Post-fire Flood Flow	Equivalent Return Interval (RI)	Ave. Bulked, Post-fire Flood Flow	Equivalent Return Interval (RI)								HD/D	Height of water relative to top of inlet, above (+), below (-) (ft)	HD/D	Height of water relative to top of inlet, above (+), below (-) (ft)	HD/D	Height of water relative to top of inlet, above (+), below (-) (ft)	HD/D	Height of water relative to top of inlet, above (+), below (-) (ft)
Acorn	20	53	35	3	94	39	0.14	0.07	20	0.19	133										
Clear1	149	378	233		590		0.07	0.07	139	2.93	1604										
Clear2	153	389	237	4	600	68						Box culvert inlet, 2'h x 12'w	90	1.5	1	5.8	9.6	2.6	3.2	>10	>10
	153	389	237		600							Arch Culvert, 6'h x 12'w	463	0.44	-3.36	0.89	-0.66	0.61	-2.34	1.4	2.4
Foreman	88	223	147	4	372	43	0.10	0.07	119	2.77	1579										
Harmon1	23	61	29		78		0.11	0.06	13	0.67	79										
Harmon2	25	66	31	3	83	29	0.13	0.06	28	1.87	374	3' CMP w/ headwall	35	0.77	-0.69	1.54	1.62	0.92	-0.24	2.4	4.2
	25	66	31	3	83	29						2'h x 4'w headwall with swing gate	Fence panel designed to fail during flood								
Malosky	32	86	41	3	111	25						Box culvert inlet, headwall, 4'h x 8'w	160	0.35	-2.6	0.65	-1.4	0.41	-2.36	0.8	-0.8
	32	86	41		111							Box culvert inlet, headwall, 4'h x 5'w	100	0.48	-2.1	0.9	-0.4	0.55	-1.8	1.08	0.32
Peavine	50	130	86	4	222	46						7' CMP w/ headwall	300	<0.5	<-3.5	0.6	-2.8	0.48	-3.64	0.85	-1.05
Jamison Crk Trib.	40	106	59	3	157	36						Box culvert inlet, headwall, 3'h x 3'w	40	1	0	2.6	4.8	1.3	0.9	4.5	10.5

🟨	potentially insufficient capacity
🟧	insufficient capacity
🟥	extremely insufficient capacity