April 24th, 2023

Randall Road Debris Basin debris removal
Photo courtesy of Derek Bays, Cal OES

Montecito 2023 Storm Response

Mission Task #2023-SOC-94072

Cal OES
GOVERNOR'S OFFICE OF EMERGENCY SERVICES

California Department of Conservation
California Geological Survey

Overview

In response to the 2023 atmospheric river events and subsequent debris flows, the Cal OES Watershed Task Force mission tasked California Geological Survey (CGS) to perform an assessment to identify scope and scale of ongoing debris flow risk to Montecito and surrounding communities. CGS performed an assessment that included field observations and a desktop mapping review of several sources of remote sensing data to capture in-channel conditions along several key watersheds. The observations and conclusions were then captured in the attached report.

The study's findings are intended to assist local and emergency responding agencies in the development of more detailed assessments and potential emergency response plans. However, it is important to note that the observations and conclusions included in this memo are not intended to be fully comprehensive and/or conclusive, but rather to serve as a preliminary tool to assist in scoping future studies and developing potential mitigations and/or management plans.

Key Points

1. Watersheds in the Santa Ynez Mountains upslope of Montecito have been significantly loaded with sediment from approximately 1,162 landslides produced by this year's storm events. This sediment is positioned to be mobilized during future debris flow events.
2. During periods of high soil moisture and high runoff potential, the following scenarios have potential to produce debris-laden flows that may exceed the conveyance capacity of channels:
   - Multiple consecutive high-frequency (1- to 2-year Recurrence Interval), short duration (< 2-hour) storms that result in moderate runoff events in rapid succession.
   - A single, low-frequency (> 5-year Recurrence Interval), short duration (< 2-hour) storm that results in high-magnitude runoff.
3. CGS observed Romero Creek to be a particularly sensitive drainage as it yielded the most debris flow volume per watershed area.

Cal OES Contact Information

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California
Department of Conservation
California Geological Survey

Gavin Newsom, Governor
David Shabazian, Director

MEMORANDUM

DATE: April 6, 2023

TO: Derek Bays, PG
Engineering Geologist
Governor's Office of Emergency Service
3650 Schriever Ave.
Mather, CA 95655

SUBJECT: Montecito 2023 Storm Response – Cal OES Mission Task #2023-SOC-94072

Introduction and Background

Heavy rainfall during a January 2023 atmospheric river (AR) storm sequence triggered significant floods and landslides that directly impacted the downstream communities of Santa Barbara, Montecito and Carpinteria in Santa Barbara County, California. The concentrated rainfall that occurred on the south-facing slopes above Montecito on January 9, 2023, generated debris flows that transported large volumes of sediment through channels, filled downslope debris basins, and overtopped channel banks. As a result of this damage, the California Geological Survey (CGS) was previously mission tasked by the California Governor's Office of Emergency Services (Cal OES) to evaluate the condition of debris basins and in-channel conveyance capacity, as summarized in a memorandum dated January 27, 2023 (Cal OES Mission Task #2023-SOC-89041; Appendix A).

In the previous memo to Cal OES, based upon limited field review and aerial photo interpretation, the primary source of debris mobilized on January 9, 2023, along mainstem channels upstream of Montecito (Cold Spring, Hot Springs, San Ysidro, and Romero Creeks) appears to have mostly originated within the mainstem channels through scour (incision) and bank slough, and to a somewhat lesser extent by landslide activity along tributary slopes immediately flanking the mainstem channels. However, source areas high in the watersheds appeared to have been impacted by landslides, including shallow debris slides that transitioned into debris flows as they progressed downslope and appeared to contribute and re-load the upper channels with colluvium. CGS identified that the volume of landslide-generated sediment stored high in the watersheds was unknown. Thus, the risk of sediment being mobilized during high- flows from subsequent storms and impacting the downstream community of Montecito was uncertain.

To more accurately understand the future downstream life-safety risk to the community of Montecito, CGS was again mission tasked by Cal OES in February 2023 to provide more detailed information on landslide and sediment volume distribution within the upslope watersheds. Using a mix of remote-sensed products (satellite and fixed-wing aerial imagery) and field-based observations, CGS was tasked to:

- Characterize the spatial distribution of landslides within principal watersheds above Montecito, CA.
- Estimate sediment availability within existing mainstem channels.
- Evaluate landslide volumes delivered to watercourses that may be entrained in future storm events.
- Characterize near-term runoff-induced hazards associated with bulked flood and debris flows that may occur in subsequent storm events.

In the following memo, we provide a timeline of the work completed, a description of the physical characteristics of the study area, rainfall accumulation and runoff information for the principal watersheds above Montecito, desktop review and field measurements of landslides, results of landslide volume estimates, and a discussion of the future downstream risk to the community of Montecito.

The desktop review and field work presented herein for areas upslope of the community of Montecito was completed as part of a larger, more detailed study currently underway to evaluate potential post-fire effects and characterize how they may influence shallow landslide activity in the years following fire. This more detailed study is being performed through an ongoing collaboration between multiple agencies and university partners, including CGS, the United States Geological Survey (USGS), the United States Forest Service (USFS), and the University of California at San Diego (UCSD). Key collaborating members from each organization include:

CGS	USGS	USFS	UCSD
Don Lindsay, CEG, GE (Lead)	Dr. Matt Thomas (Lead)	Jonathan Schwartz (Lead)	Dr. Neal Driscoll (Lead)
Brian Swanson, CEG	Dr. Jason Kean		
Rebecca Rossi	Dr. Francis Rengers		
Dr. Nina Oakley	Jaime Kostelnik		

Timeline of Work Completed

The following work was completed in fulfilling the objectives:

- Early February 2023, USGS team performed desktop mapping of landslides within the principal watersheds above Montecito using a mosaic of orthoimagery that was collected by the Civil Air Patrol (CAP) and dated to January 18, 2023.
- February 19, 2023, CGS, USGS and USFS (team) mobilized to Montecito.
- February 20 through 23, the team conducted field work to collect measurements of a subset of landslides identified in the CAP imagery and perform reconnaissance of in-channel conditions along portions of Cold Spring, San Ysidro, and Romero Creeks.
- February 24, CGS and USGS conducted a close-out meeting with team members and demobilized back to home offices.
- March 1 through 3, CGS performed additional desktop mapping of landslides within the principal watersheds above Montecito using Fire-Integrated Real-Time Intelligence System (FIRIS) aerial imagery dated February 16, 2023. The FIRIS imagery provided additional images of

landslides that were otherwise difficult to identify due to shadows on north-facing slopes in the CAP imagery.
- April 6, 2023, staff finalized this memo.

Study Area Description

The study area spans seven principal watersheds above Montecito, California, from the western Cold Spring Canyon watershed to the eastern Romero Creek watershed (Figure 1). The upper portion of these watersheds are all located within the Los Padres National Forest and were largely burned at moderate to high soil burn severity during the 2017-18 Thomas Fire. These principal watersheds have historically generated debris flows which have resulted in damage to the downstream built environment of Montecito (Kean, et al., 2019, Oakley, et al., 2018, United States Army Corps of Engineers, 1974, and Stubchaer, 1969). This study focuses on landslide sediment contributed from upper areas of the watersheds. Therefore, the southern boundary of the study area is truncated to exclude landslides in developed areas.

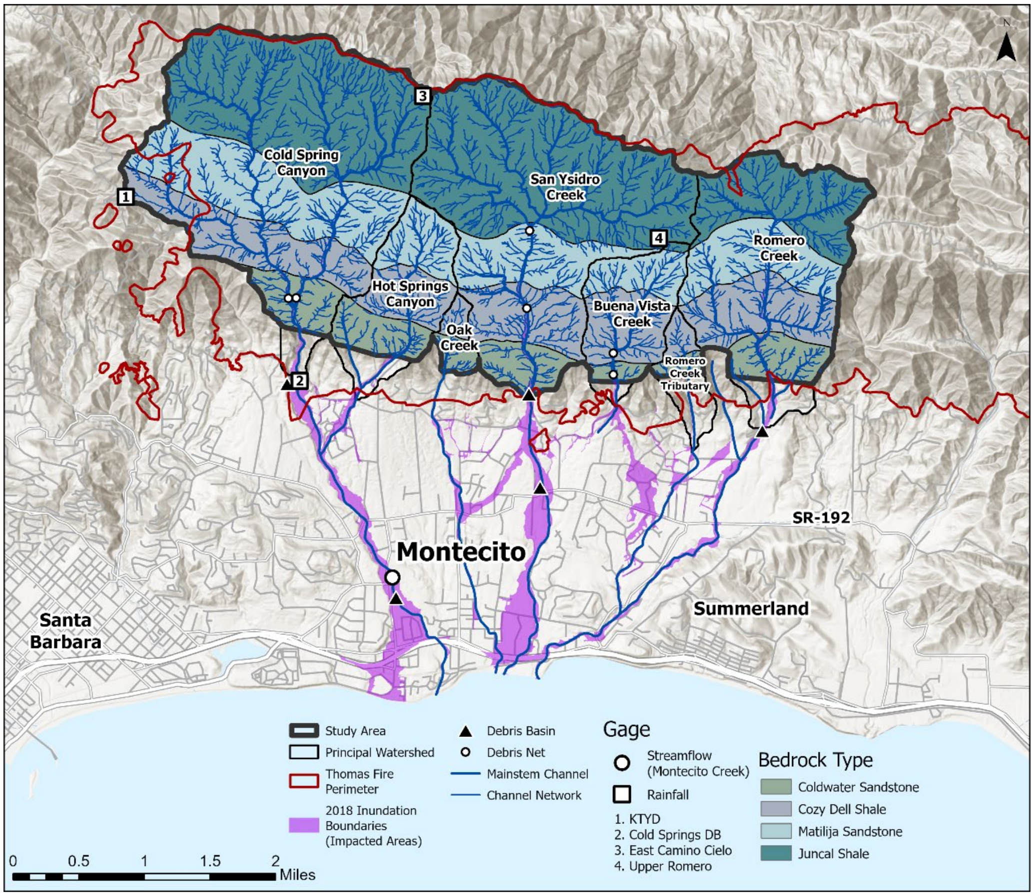

Figure 1. Map showing the bedrock types and seven principal watersheds within the study area.

Landslides that were triggered during the January 9, 2023, AR occurred across different bedrock (Figure 1 and Figure 2; Table 1; Dibblee and Ehrenspeck, 1986a and 1986b) and vegetation types. The study area is located within the Santa Ynez Mountain range and is underlain predominantly by steeply dipping marine sandstones and hard shale beds of Eocene age. The sandstone beds are typically more competent than the shale beds, support steep to precipitous slopes, and are the source of cobbles and boulders that can accumulate within channels. The rugged topography and shallow soils provide suitable habitat for dense chaparral brush. The channel network from the ridge tops (3,800 feet in elevation) to the bottom of the principal watersheds (530 feet in elevation) is steep and dense throughout the study area. The maximum topographic slope is 85 degrees with an average slope of 36 degrees.

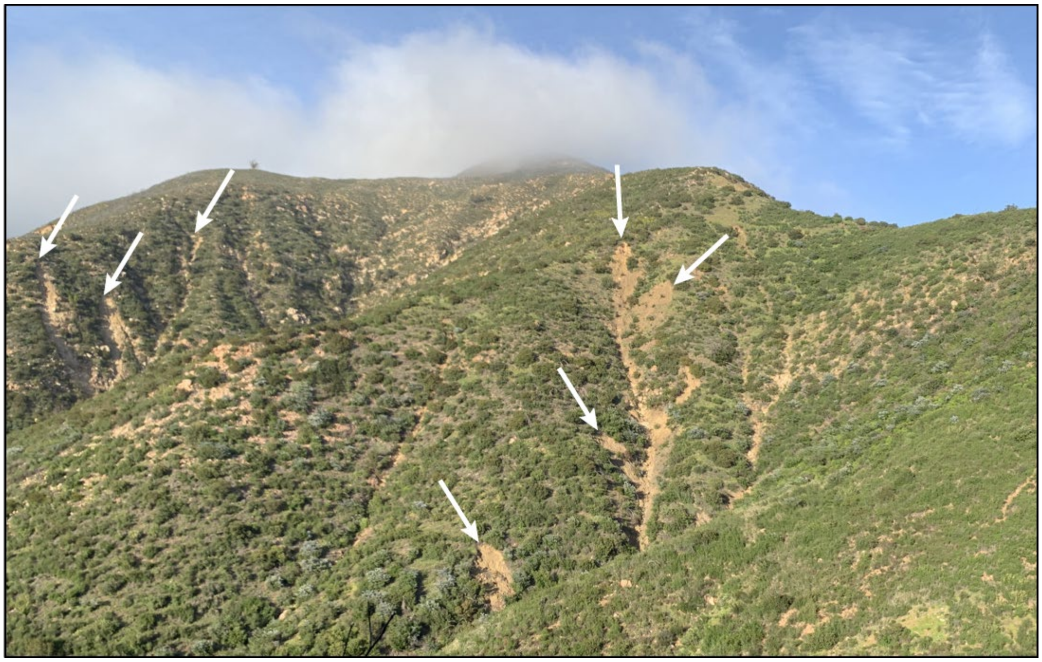

Figure 2. Representative photo of shallow landslides that were triggered during the January 2023 AR sequence. White arrows point to initiation locations of multiple landslides located in the headwaters of the Cold Spring Canyon watershed. Landslide sediment was transported along runout paths to upland colluvial hollows and creeks.

Table 1. Bedrock types within the study area.

Bedrock Type	Description
Coldwater Sandstone	Hard sandstone interbedded with siltstone and shale
Cozy Dell Shale	Silty shale with minor sandstone
Matilija Sandstone	Medium- to fine-grained, hard, well-cemented sandstone with thin to thick interbeds of shale
Juncal Shale	Shale interbedded with hard sandstone

Storm Event and Runoff

Storm rainfall accumulation and annual flood recurrence intervals (RI) for the January 2023 AR sequence are summarized in the previous CGS memo (Appendix A). CGS further characterized the rainfall distribution during the January 9, 2023, AR event within the localized study area. A moderate/strong AR impacted the study area beginning around midnight to 1 a.m. on January 9, 2023. The AR stalled over this region for approximately 18 to 24 hours, producing persistent rainfall (Figure 3).

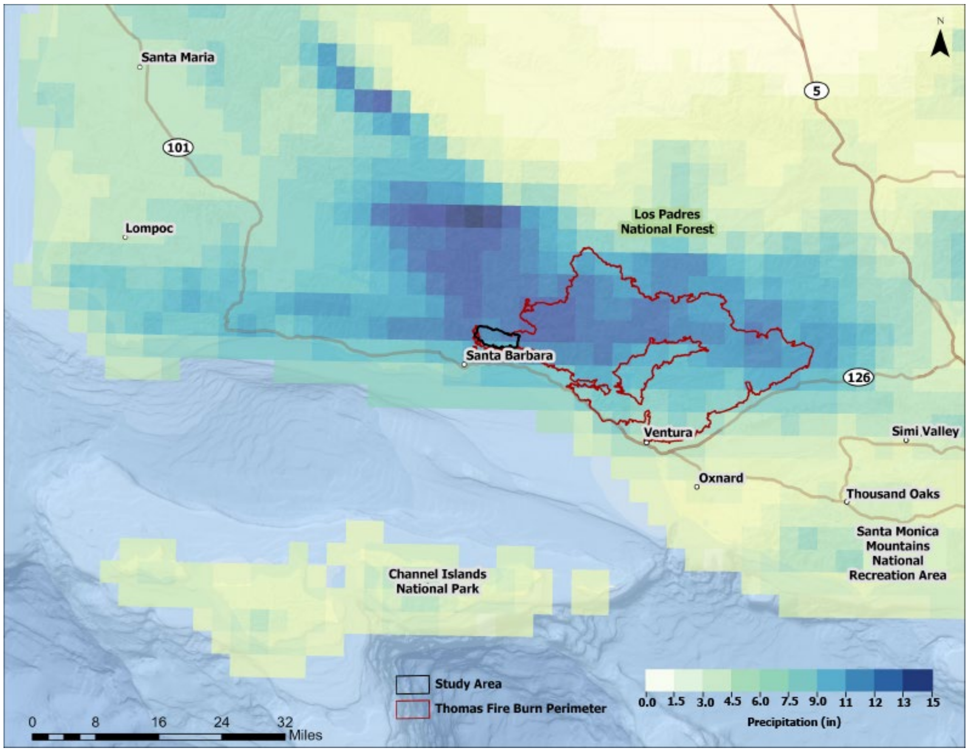

Figure 3. Total precipitation in inches (data from PRISM accessed through climateengine.org) from January 8 to11, 2023 across study area (PRISM Climate Group, Oregon State University, 2023).

Conditions were very favorable for orographic ascent, leading to persistent moderate-to-high hourly rain rates (e.g., 0.5-1 inches+ per hour; <2-Year RI) with peak rainfall occurring during a four-hour window (10 a.m. to 1 p.m., Pacific Standard Time (PST) across the four rain gages in the study area (Figure 1 and Figure 4). The average maximum 1-hour rainfall accumulation observed among the four rain gages was 0.96 inches, with the highest 1-hour rainfall accumulation of 1.11 inches (~2-Year RI) recorded at the KTYD rain gage (Figure 1) on the southwestern extent of the study area. The KTYD gage experienced a secondary peak rainfall accumulation of 0.99 inches during the evening on January 10, 2023, associated with an isolated thunderstorm. Most landslides are presumed to have occurred sometime on January 9 based on the timing of slide movement and impacts documented in 911 records and in time-stamped imagery and video provided by Santa Barbara County and Montecito Fire Department.

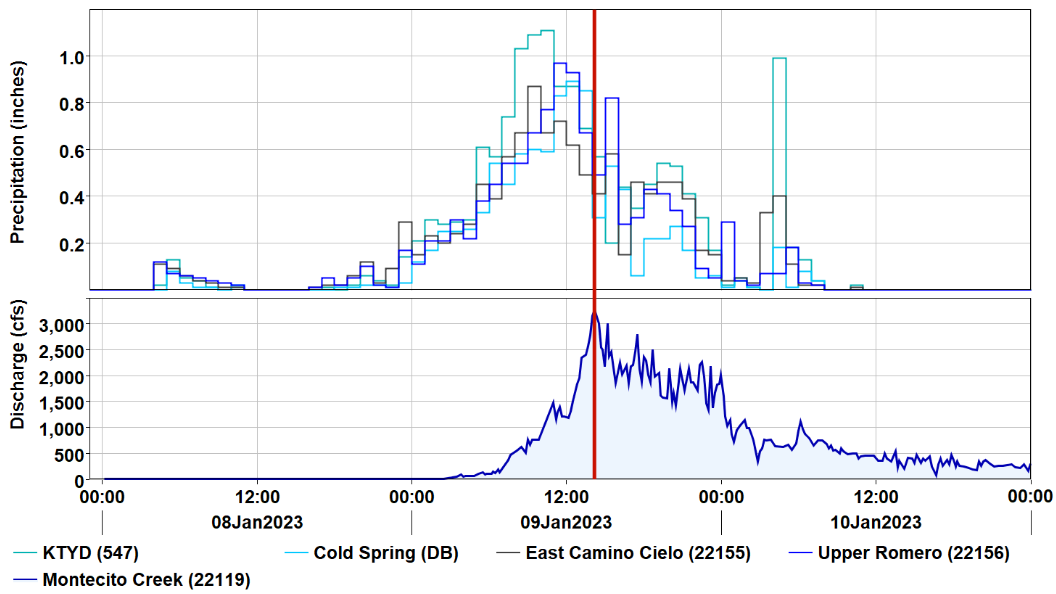

Figure 4. Hourly rainfall accumulation from January 8 to 11, 2023 at rain gages distributed throughout the study area (Figure 1; SBC, 2023). Red vertical line indicates the timing (i.e., 14:10:28) of peak flow (i.e., ~3,200 cubic feet per second) that occurred at the downstream Montecito Creek gage (22119) approximately 1 hour after peak rainfall occurred within the upslope watersheds.

Landslide Distribution – Aerial Imagery Interpretation

CGS and USGS produced a geomorphic landslide map using aerial imagery taken shortly after the January 9, 2023, AR event (CAP dated 01/18/2023 and FIRIS dated 02/16/2023) to quantify the number and distribution of recent landslide failures. Landslide initiation locations were identified wherethe recency of movement was apparent as the eroded sediment and scars within the head scarp and runout paths appeared brighter or more orange to brown in color in the aerial imagery (Figure 5A). Additionally, pre-event aerial imagery (2022) and post-event lidar were used to compare with the recent CAP and FIRIS imagery to identify newly activated landslides (e.g., vegetation cleared from runout path) and to differentiate from pre-existing landslide scars, scoured channels, or debris-flow runout paths. Due to the resolution of the CAP and FIRIS aerial imagery, the minimum width of mappable head scarp features is estimated to be about 6-9 feet wide. Features narrower than this dimension were considered non-mappable and, therefore, are not included.

Each landslide that was identified on the aerial imagery was classified as a “natural” or “modified” landslide based on the state of slope conditions they were associated with. Landslides that occurred along modified slopes, including cutbanks and fill slopes associated with roads or in developed areas at the southern extent of the study area were classified as “modified” landslides. Landslides without an association with anthropogenic influences, such as roads, house pads, overtopped crossings and watercourse diversions were classified as “natural” landslides. Figure 5B shows all landslides that were mapped with aerial imagery across the study area.

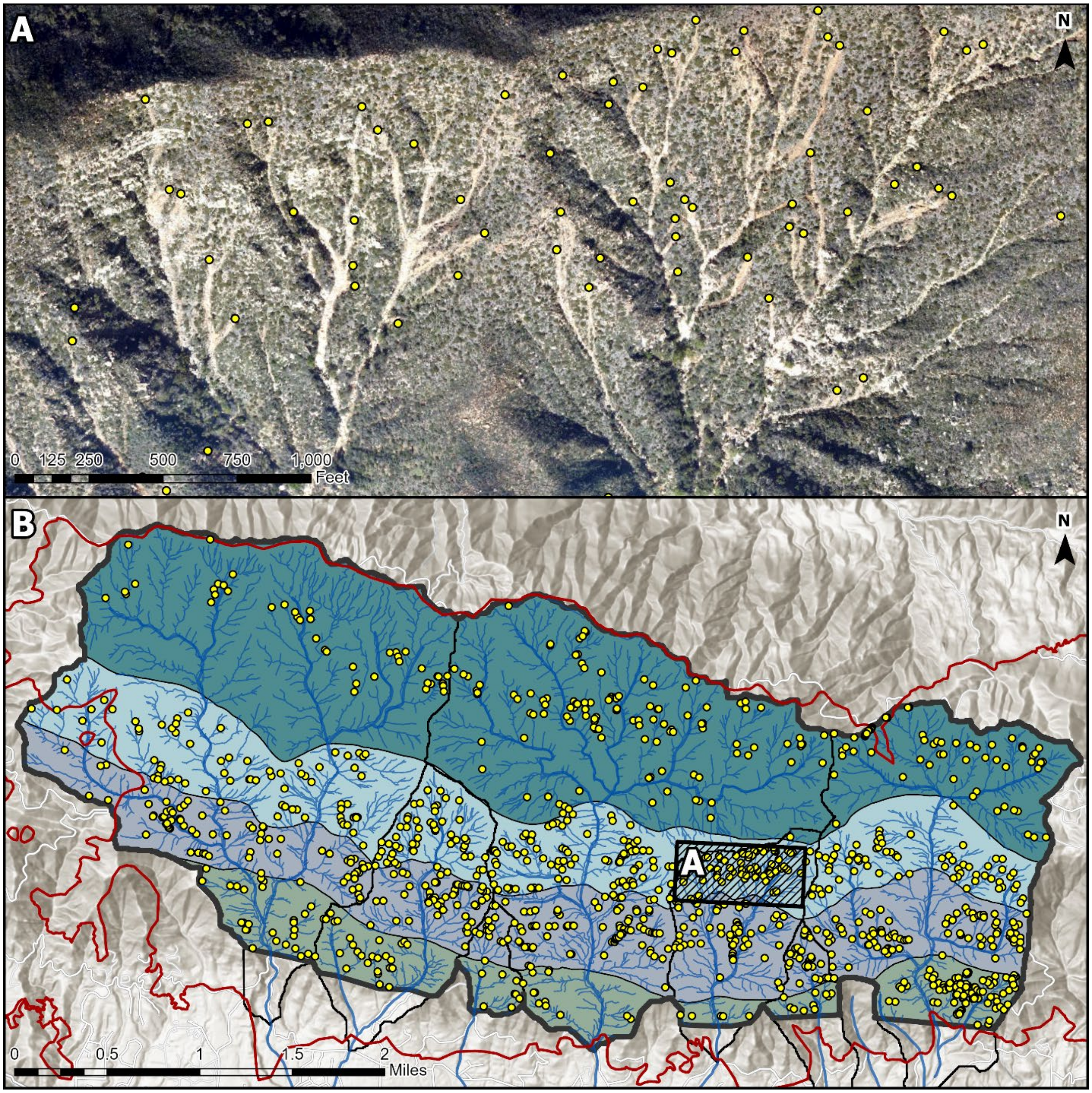

Figure 5. A. Landslide initiation locations (yellow points) and runout paths identified on aerial imagery within a portion of the Buena Vista Creek watershed (see detailed location in B). B. Distribution of landslide initiation locations within the study area mapped from FIRIS and CAP aerial imagery relative to drainage pattern and underlying bedrock (see Figure 1 for geologic unit and map symbology explanation).

Field Observations

The CGS, USGS, and USFS collected field measurements in selected areas across different bedrock and vegetation types as a representative subset of the landslides mapped during the desktop review. A laser range finder and tape measure were used to measure the average width, length, depth, and inclination of the source area of each landslide (Figure 6). The source area is where the landslide initiated and produced sediment or colluvium that was transported from the head scarp of the landslide downslope and into first-order channels. In many locations we observed additional scour of hillslope sediment downslope of the source area, causing flows to become further bulked as they progressed downgradient. Thus, the average volume estimated from our field measurements represents a minimum volume attributed to landslide source areas. The mapped landslides and field measurements were then used to obtain landslide statistics, including total number and density of landslides within the study area and within each bedrock type, as well as estimates of the minimum sediment volume generated from the total sample of landslides within the study area.

Relevant observations of landslide runout distance were collected where possible to determine where and how far the sediment was transported during the landslide. These observations provided information about where and how much sediment is currently stored in colluvial hollows on the hillslope and along first-order channels. Landslide runout paths that entered first-order channels were followed to the mainstem to track where colluvium was being transported, reworked and stored within portions of the Cold Spring Canyon and San Ysidro Creek watersheds.

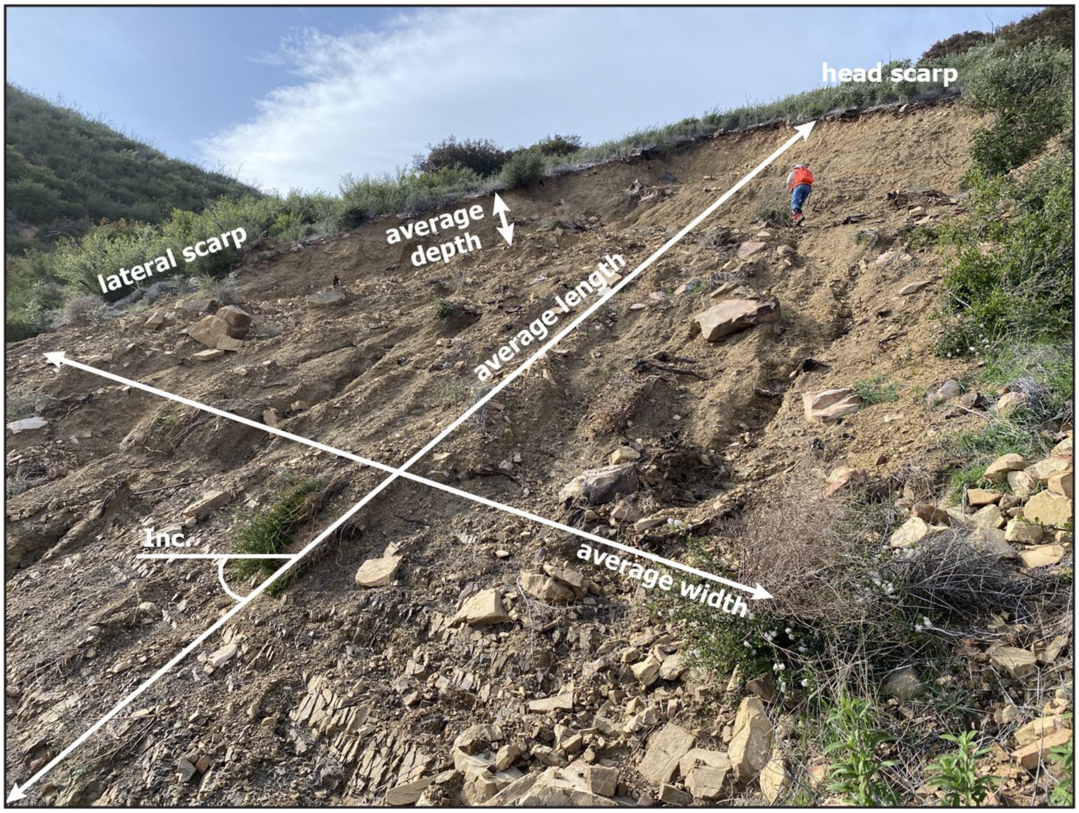

Figure 6. Example of the field measurements that were collected at each landslide source area (average width, length, depth and inclination). This landslide source area is located within the Juncal Shale bedrock type. The average length of the landslide source area shown extends off the photo.

Results

Landslide Density and Volume

The January 9, 2023, AR event triggered an estimated 1,162 shallow landslides within the study area (Figure 5B). Of the 1,162 shallow landslides, 952 were classified as natural landslides and the remaining 210 as modified landslides. Table 2 summarizes the total number of landslides and landslide densities that occurred across the study area and bedrock types in which they occurred. The Cozy Dell Shale, Coldwater Sandstone, and Matilija Sandstone contain the highest densities of 147 to 182 landslides per square mile, which is around three times the landslide density of 49 landslides per square mile within the Juncal Shale.

Table 2. Summary statistics of the landslide density (number of landslides per square mile) across the study area and with respect to bedrock types.

Density Calculation Zone	Total Number of Landslides	Total Area by Bedrock Type (square mile)	Landslide Density (No./square mile)
Study Area	**1,162**	**10**	**116**
Juncal Shale	217	4.4	49
Matilija Sandstone	353	2.4	147
Cozy Dell Shale	401	2.2	182
Coldwater Sandstone	191	1.1	174

An average depleted landslide sediment volume for each bedrock type was estimated based on field measurements of average width, length, and depth of natural landslide sources across the study area (Figure 7; Table 3). These averages vary by bedrock type. For example, the Juncal Shale, which contains a relatively low landslide density, resulted in the highest average volume per landslide of 6,824 cubic feet. Whereas the Cozy Dell Shale, which contains a relatively high landslide density, resulted in the lowest average volume of 2,524 cubic feet. Combining all measured volume estimates across all bedrock types yields a combined average volume of 4,408 cubic feet per landslide.

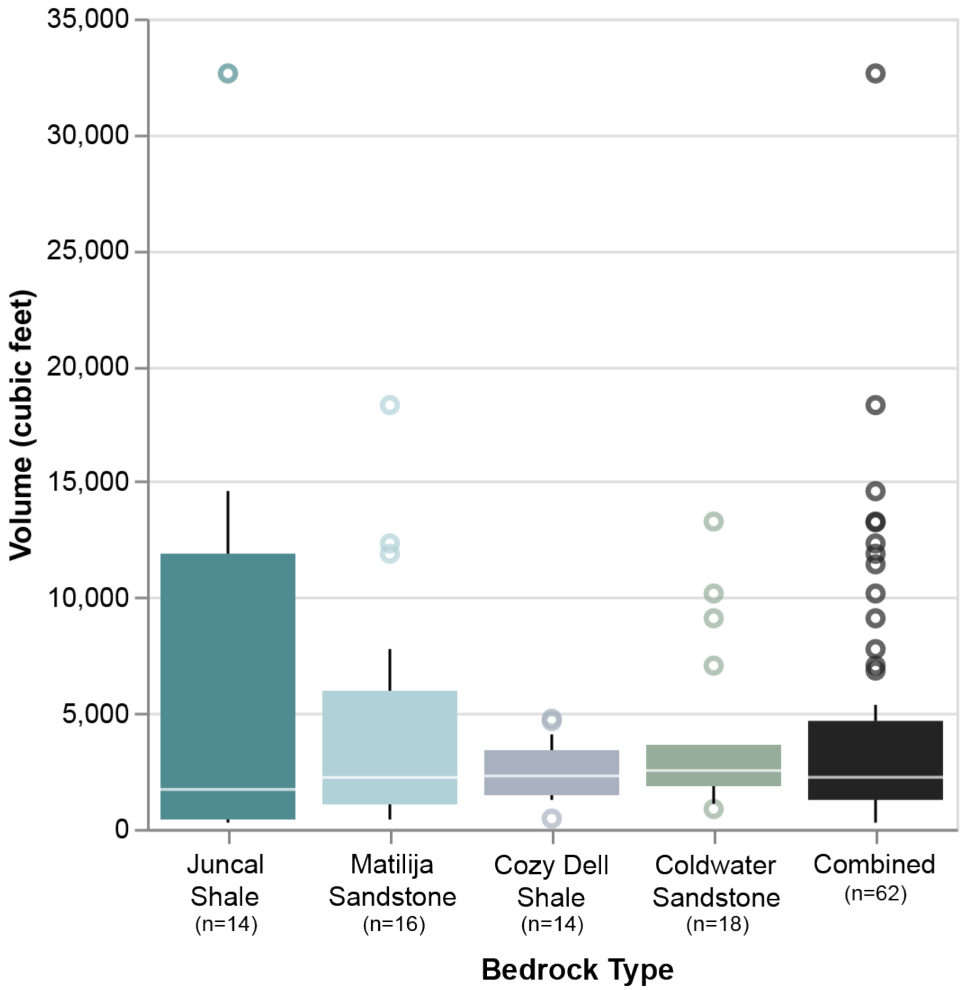

Figure 7. Box-and-whisker plots showing distribution of landslide volume measurements across the different bedrock types that were calculated from field measurements (e.g., n = 14 measurments for landslides in the Juncal Shale) of average source area width, length, and depth. Circles indicate volumes that are located 1.5 x interquartile range below the first quartile or above the third quartile of the distributions. Horizontal white line represents the median value. The combined bedrock types includes volumes derived from all of the field measurements (n = 62).

Table 3. Summary statistics for volumes (in cubic feet) calculated from the field measurements of average source area width, length, and depth across the bedrock types for landslides generated from natural slopes. Average (Avg.); Standard Deviation (SD); Minimum (Min.); Maximum (Max.); Percentiles 25th (Q1), 50th (Q2- median), and 75th (Q3).

Bedrock Type	n	Avg.	SD	Min.	Q1	Q2	Q3	Max.
Juncal Shale	14	6,824	9,241	278	509	1,706	11,773	32,631
Matilija Sandstone	16	4,129	4,953	422	1,274	2,221	4,207	18,307
Cozy Dell Shale	14	2,524	1,349	452	1,468	2,291	3,400	4,767
Coldwater Sandstone	18	4,244	3,659	865	1,947	2,652	6,201	13,278
Combined	62	4,408	5,526	278	1,290	2,288	4,741	32,631

Landslide Sediment Distribution

The distribution of recently deposited and reworked colluvial sediment following the January 2023 AR varied throughout tributary channels across the study area. Observations made along San Ysidro Creek and Cold Spring Creek appeared representative of conditions over the broader study area. Tributaries to San Ysidro Creek showed the presence of recently deposited and reworked colluvial sediment trapped directly upstream of channel blockages, such as keystone boulders (Figure 8A) positioned high within first-order channels. In lower elevations, channels showed evidence of reworked alluvium and scoured sediment indicating more scour than deposition (Figure 8B). And downgradient of depleted landslide scars, a few channel reaches contained extensive volumes of recently reworked, colluvial sediment deposits that were observed within tributaries of San Ysidro Creek (estimated volume of 5,000 cubic feet; Figure 8C) and Cold Spring Creek (estimated volume of 19,000 cubic feet; Figure 8D).

Figure 8. Amount and distribution of available sediment throughout low-order channels. A. Recently deposited and reworked, colluvial sediment within a tributary of San Ysidro Creek following the January 2023 AR event. B. Reworked channel-bed sediment within a tributary of San Ysidro Creek. C. Recently deposited and reworked, colluvial sediment within a tributary of San Ysidro Creek and (D.) Cold Spring Creek. Arrows in the photos indicate flow direction; channel widths are approximately 7 ft (A), 15 ft (B), 17 ft (C), and 30 ft (D).

The mainstem channels showed more evidence of recent bed and bank scour than deposition. Both Cold Spring and San Ysidro Creeks have recently scoured down to bedrock in many locations (Figure 9A). However, there is evidence of erodible sediment remaining within the channel and along oversteepened banks that could be entrained and transported downgradient during future runoff events. Examples of sediment currently stored within the channel bed and banks are shown in San Ysidro Creek (Figure 9B and Figure 9C)and Romero Creek (Figure 10A and Figure 10B).

Figure 9. Amount and distribution of available sediment throughout the mainstem channels. A. More evidence of scour within mainstem channels than deposition in San Ysidro and (B) Cold Spring Creeks. C. Easily erodible sediment currently located in mainstem channels is available to transport in San Ysidro Creek. Channel widths are approximately 50 ft (A and B), and 30 ft (C).

Figure 10. A. Before photo of bridge abutments in Romero Creek shortly after 1-9-2018 debris flow event. B. After photo following 1-9-2023 flood of bridge abutment showing aggregated alluvium downstream. For scale, the large boulder in (B) is approximately 15 feet wide. Arrows in the photos indicate flow direction.

Discussion

The total minimum volume of landslide-derived sediment sourced in each watershed was estimated by adding sediment contributions by bedrock type within each watershed (Figure 11). Summing the sediment contributions across the seven principal watersheds provides a total minimum volume estimate of 4.8 million cubic feet of sediment. Approximately ~77% of this total volume is contributed from the three largest watersheds (San Ysidro Creek: ~30%, Romero Creek: ~28% and Cold Spring Canyon: ~19%). However, once the total minimum volume of landslide sediment within each watershed is normalized by watershed area, we find that Romero Creek Tributary, Buena Vista Creek, and Romero Creek watershed contain the highest yield rates between 717 and 920 thousand cubic feet per square mile (Table 4). The high sediment yields in Romero Creek Tributary and Buena Vista Creek watersheds are attributed to the high density of landslides within the Matilija Sandstone and Cozy Dell Shale bedrock types. The high sediment yield rate in the Romero Creek watershed is attributed to higher landslide density within the Coldwater Sandstone bedrock type.

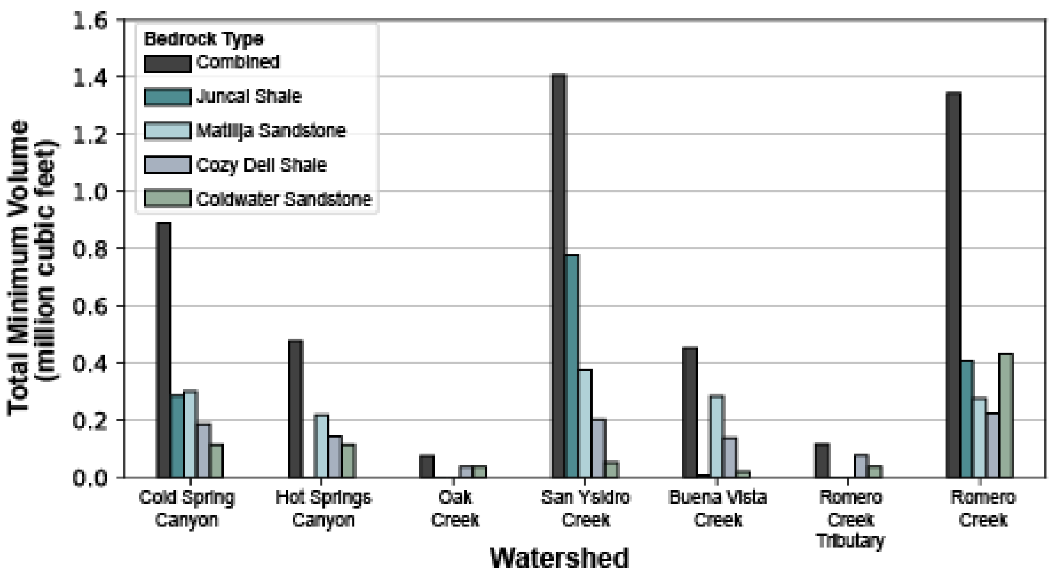

Figure 11. Total minimum volume of landslide sediment by bedrock type within each watershed. Combined bedrock type is the total minimum volume summed from all bedrock types within each watershed.

Table 4. Total minimum volume of landslide sediment by bedrock type within each watershed normalized by watershed area.

Watershed	Landslide Count	Volume (thousand cubic feet)	(square mile)	Normalized Volume (thousand cubic feet/ square mile)
Cold Spring Canyon	196	889	3.57	249
Hot Springs Canyon	112	477	0.73	653
Oak Creek	13	76	0.13	585
San Ysidro Creek	272	1,407	3.01	467
Buena Vista Creek	126	452	0.63	717
Romero Creek Tributary	34	116	0.12	970
Romero Creek	199	1,344	1.85	726

The estimated total volume of landslide sediment was limited by the rapid assessment of aerial imagery and field measurements and should be treated as a minimum estimate. There were many locations where additional scour of channels and hillslopes occurred downslope of the source area resulting in increased sediment volume transport that was not included in the average width, length and depth measurements used to calculate the landslide volumes. The number of landslides is also dependent on the visibility of the landslide initiation zones on the aerial imagery, and it is likely a minimum landslide count. Field measurements were collected across representative geologic conditions but were limited to accessible areas that contained higher densities of small to medium-sized landslides.

Most runout paths observed from the landslide initiation points in the field and traced on aerial imagery reached colluvial hollows or first-order drainages but did not appear to fully or continuously recharge the low-order channel network with sediment. Some low-order channels, like those visited in the San Ysidro Creek and Cold Spring Canyon watersheds contained only alluvium without excessive scour or deposition. To contextualize the total volume of landslide sediment that potentially recharged channels above Montecito, we compare the total minimum landslide volume reported herein against published volumes that were quantified and reported in Kean et al. (2019) following the January 9, 2018, debris flows. Results indicate that the 4.8 million cubic feet of potential recharge of landslide sediment following the January 2023 AR events is about 20% of the total volume discharged following the January 9, 2018, debris flows, with most of the recharge occurring within Romero and Buena Vista Creek watersheds, at about 41% and 31%, respectively. Therefore, when evaluating the volume of recharge over the entire study area (all seven watersheds combined), the volume of recent landslide-derived sediment that can be remobilized by a large runoff event of similar magnitude as the January 9, 2018, event is relatively low; however, it increases to moderate for Buena Vista and Romero Creek watersheds.

Table 5. Total minimum volume of landslide sediment normalized by watershed area in this study compared to the observed sediment volume from the 1/9/2018 DF events (Kean, et al., 2019).

Watershed	Kean et al. (2019) (Thousand cubic feet)	This Study: Total Minimum Volume (Thousand cubic feet)	% of 1/9/2018 DF
Montecito Creek*	8,160	1,370	17%
Oak Creek	353	76	22%
San Ysidro Creek	10,500	1,410	13%
Buena Vista Creek	1,450	452	31%
Romero Creek**	3,530	1,460	41%
Combined	24,000	4,760	20%

*Montecito Creek (Kean et al., 2019) is equivalent to Cold Spring Canyon and Hot Springs Canyon watersheds (this study).
** Romero Creek (Kean et al., 2019) is equivalent to Romero Creek and Romero Creek Tributary watersheds (this study).

Although detailed hydrologic and hydraulic analyses were not performed as part of this study, the impact of potential hydrologic scenarios with the current sediment conditions can be inferred from observations from recent storm events. During periods of low soil moisture and low to moderate seasonal runoff potential (expressed as a function of the Antecedent Index (AI) of > 6.0 in accordance with the Santa Barbara County Hydrology Report (SBC, 2020), the available storage capacity within existing debris basins appears adequate to mitigate anticipated runoff hazards triggered by relatively common (RI of < 5 year) rainfall intensities at durations of 0.5 to 1.5 hours, which is typically the length of time required for runoff to travel from the top of the mountain divide and exit at the mountain front above Montecito (i.e., peak storm intensities at durations roughly equal to the time of concentration). However, maintenance must be performed to keep debris basins and channels free of significant accumulated sediment and debris.

During periods of high soil moisture and high runoff potential (i.e., AI $\leq$ 6), the following scenarios may cause runoff and debris loading that may begin to impact the storage capacity of debris basins and allow sediment- and debris-bulked flows to overwhelm channel and crossing capacities downstream:

- Multiple high-frequency (1- to 2-year RI), short duration (< 2-hour) storms that result in moderate runoff events in rapid succession that can in-fill debris basins without sufficient time between events for maintenance activities to reduce accumulated debris.
- A single, low-frequency (> 5-year RI), short duration (< 2 hour) storm that results in high-magnitude runoff that can infill basins and start to exceed the conveyance capacity of channels under bulked-flow conditions.

Furthermore, in the event the slopes are impacted by wildfire and the existing vegetation is once again removed and the upper soil horizon altered, regardless of antecedent moisture conditions, it is likely that post-fire runoff and debris flows can be triggered during high-frequency (estimated to be < 2-yr return interval) rainfall events that may overtop debris basins and impact the built environment downstream (Kean, et al., 2019).

Future Proposed Work

As discussed, CGS, USGS, USFS, and UCSD are currently working in collaboration on a larger study to evaluate post-fire effects on landslide failures and the potential long-term impacts the landslide failures may have on sediment supply to channels upslope of communities within Santa Barbara County. Future work proposed under this collaboration includes the following:

- Conduct additional drone-based, field, and desktop mapping to quantify the spatial distribution of stored sediment in low-order channel networks.
- Expand sample size of field-based measurements at landslide locations across different bedrock and soil conditions.

- Evaluate landslide occurrence and volume across different slope morphometrics (slope gradient, aspect, concavity/convexity, tributary area).
- Expand desktop and field assessment to a larger area impacted by the Thomas Fire and adjacent fires of various ages (e.g., Jesusita and Cave Fires).
- Evaluate vegetative conditions in and upslope of landslide source areas using drone aerial imagery (led by UCSD) and collect additional field measurements of root cohesion and root density.

Conclusion

Under Cal OES Mission Task #2023-SOC-94072, CGS, along with assistance from our partners, (1) characterized the spatial distribution of landslides within principal watersheds above Montecito, CA, (2) evaluated landslide volumes delivered to watercourses that may be entrained in future storm events, and (3) characterized near-term, runoff-induced hazards associated with bulked flood and debris flows that may occur in subsequent storm events.

Our findings indicate that at least 1,162 landslides occurred within the study area, resulting in a minimum total volume of approximately 4.8 million cubic feet (~176,000 cubic yards) of recent landslide sediment entering channels. Most of the sediment appears to occupy low-order channels high in the watersheds and will likely migrate downstream during subsequent storm events. Lower main-stem channels appear to be locally depleted of sediment relative to conditions leading up to the January 9, 2018 debris flow event, but continue to have ample available sediment that can be entrained primarily through bank sloughing and secondly through incision and scour of in-channel sediment that could become mobilized and, due to its proximity to the mountain front, contribute to infilling of debris basins and potentially impact the community of Montecito.

The downstream flood and debris-flow life-safety risk within Montecito is dependent upon future soil moisture, vegetative cover, and weather conditions. Under moderate to dry soil-moisture conditions, and in the presence of a dense vegetative cover, it is likely the watersheds above Montecito can accommodate storms of moderate frequency (RI of < 5-years) at durations < 2 hours with minimal adverse impacts. However, as the soil moisture increases and/or the vegetative cover is impacted by wildfire, the watersheds may become susceptible to high-frequency storms (< 2-year RI) of shorter duration rainfall (< 1-hour) that could generate sufficient runoff to entrain and transport material that may overwhelm the debris basins and reduce channel conveyance capacity downstream. This may lead to increased debris loading and flooding that could impact the community of Montecito and nearby highway infrastructure.

Limitations

The observations and conclusions included in this memo are not intended to be fully comprehensive and/or conclusive, but rather to serve as a preliminary tool to assist local and emergency responding agencies (e.g., Santa Barbara County, Montecito Fire, Governor's Office of Emergency Services, and other responsible agencies) in the development of more detailed assessments and potential emergency response plans. It is intended that the emergency responding agencies will use the information presented in this memo as a preliminary guide to assist in scoping future studies and developing potential mitigations and/or management plans.

Please do not hesitate to contact us if you have any questions.

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Attachments:

References

Appendix A

References

Campbell, R. (1975). *Soil slips, debris flows, and rainstorms in the Santa Monica mountains and vicinity, southern California.* United States Geological Survey. Professional Paper 851.

Dibblee, T., & Ehrenspeck, H. (1986a). Geologic Map of the Carpinteria Quadrangle. *Dibblee Geological Foundation, Dibble Foundation Map DF-04*.

Dibblee, T., & Ehrenspeck, H. (1986b). Geologic map of the Santa Barbara quadrangle. *Dibblee Geological Foundation, Dibblee Foundation Map DF-06*.

Kean, J., Staley, D., Lancaster, J., Rengers, F., Swanson, B., Coe, J., . . . Lindsay, D. (2019). Inundation, flow dynamics, and damage in the 9 January 2018 Montecito debris-flow event, California, USA: Opportunities and challenges for post-wildfire risk assessment. *Geosphere*, 1140-1163. doi:https://doi.org/10.1130/GES02048.1

Oakley, N., Boldt, F., Dumas, J., & Ralph, F. (2018). Origins and variability of extreme precipitation in the Santa Ynez River Basin of Southern California. *Journal of Hydrology*, 164-176.

Oakley, N., Cannon, F., Munroe, R., Lancaster, J., Gomberg, D., & Ralph, F. (2018). Brief communication: Meteorological and climatological conditions associated with the 9 January 2018 post-fire debris flows in Montecito and Carpinteria, California, USA. *Nat. Hazards Earth Syst. Sci.*, 3037-3043. doi:https://doi.org/10.1016/j.ejrh.2018.09.001

PRISM Climate Group, Oregon State University. (2023, Jan 11). *PRISM Climate Data*. Retrieved Mar 01, 2023, from https://prism.oregonstate.edu

SBC. (2020). *Santa Barbara County Hydrology Report: Precipitation, Rivers/Streams, & Reservoirs, Water-Year 2020.*

SBC. (2023, Jan 11). *(County of Santa Barbara Public Works)*. Retrieved Mar 01, 2023, from Santa Barbara County Real-time Rainfall, River-Stream, and Reservoir Data: https://rain.cosbpw.net/

Stubchaer, J. (1969). 1969 Floods. *Santa Barbara County Flood Control & Water Conservation District*.

United States Army Corps of Engineers. (1974). Flood plain information: Montecito Streams, vicinity of Montecito, Santa Barbara County, California. *Los Angeles District*.

Appendix A

Montecito 2023 Storm Response – Cal OES Mission Task #2023-SOC-89041

California
Department of Conservation
California Geological Survey

Gavin Newsom, Governor
David Shabazian, Director

MEMORANDUM

DATE: January 27, 2023

TO: Derek Bays, PG
Engineering Geologist
Governor's Office of Emergency Service
3650 Schriever Ave.
Mather, CA 95655

SUBJECT: Montecito 2023 Storm Response – Cal OES Mission Task #2023-SOC-89041

Introduction and Background

In response to winter storms affecting watersheds burned by the Thomas Fire, and the downstream community of Montecito, the California Geological Survey (CGS) was mission tasked by the California Office of Emergency Services (Cal OES) to assist the County of Santa Barbara in the protection of life-safety and property by supporting debris removal efforts for the purpose accommodating additional debris from storm runoff and debris flows.

January 9, 2023, California was impacted by a sequence of atmospheric river events between late December 2022 and mid-January 2023, resulting in cumulative precipitation in excess of 12 inches across large areas of the state (Figure 1). During this period, three atmospheric river systems account for most of the reported rainfall totals; the first on December 31, 2022, the second on January 4, 2023, and the third on January 9, 2023. The January 9, 2023, storm occurred on the five-year anniversary of a post-fire debris flow event that impacted the community of Montecito following the 2017/2018 Thomas Fire.

The January 9, 2023, event was particularly impactful in southern California where it resulted in heavy rainfall across south-facing slopes upslope of the communities of Santa Barbara, Montecito, and Carpentaria in Santa Barbara County, California. Storm-related impacts were concentrated in and downslope of the 2018 Thomas Fire burn scar that resulted in an evacuation order for the community of Montecito. Damage resulting from the January 9, 2023, event was significant to Montecito due to flooding and landsliding, and subsequently triggered CalOES to mission task the California Geological Survey to provide two engineering geologists/geotechnical engineers to:

- Coordinate with Santa Barbara County Public Works,
- Rapidly evaluate the current and immediate future hazards in the event of subsequent storms,
- Provide technical support and oversight to the 649th Engineer Battalion of the California National Guard (CNG) tasked with debris removal from the Randall Road Debris Basin, and
- Prepare and submit this memo outlining the work performed.

In the following, we provide a timeline of the work completed, a review of rainfall accumulation and runoff information, a description of the observed impacts resulting from the January 9, 2023, event, and documentation of the work completed by the CNG to rapidly mitigate future impacts during subsequent storm events.

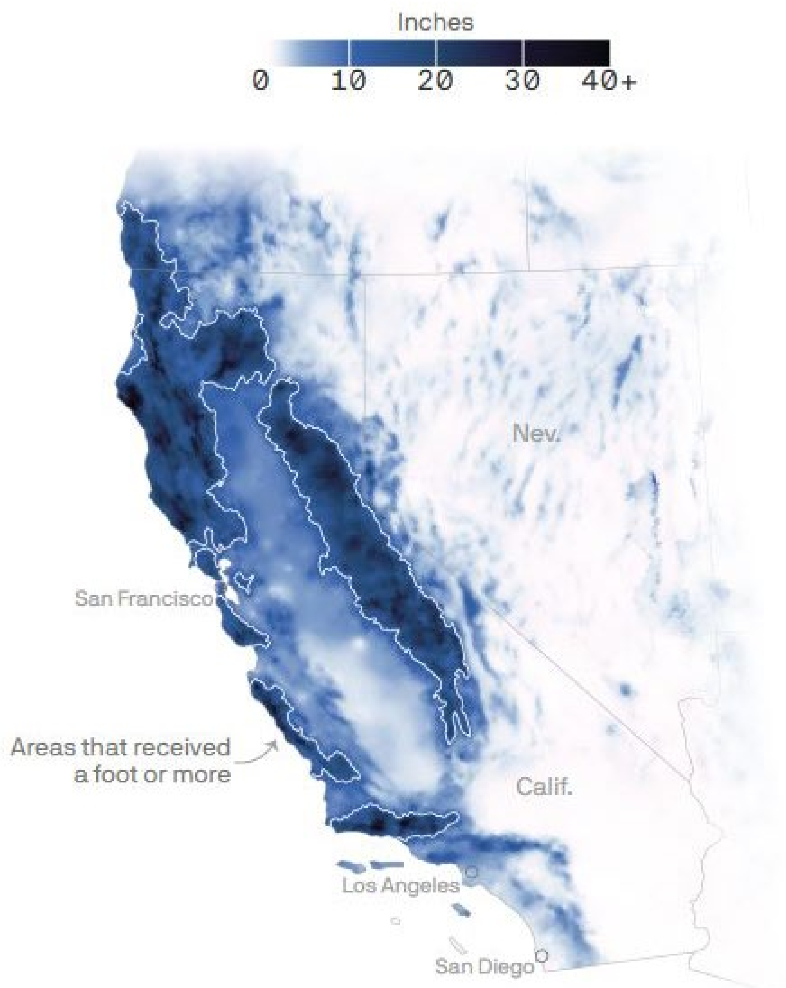
Timeline of work completed

The following work was completed in fulfilling the requested services:

- January 13, 2023, the CGS team mobilized to Montecito, California.
- January 14 and 15, 2023, the CGS team coordinated with Santa Barbara County (SBC) personnel and representatives with the California National Guard (CNG) and conducted field work to identify the condition of known debris basins and in-channel conveyance capacity
- January 16, 2023, the CGS team conducted a close-out meeting with the SBC and CNG and demobilized back to our home offices.
- January 26, 2023, staff finalized this report.

Storm Event and Runoff

To characterize the January 9, 2023, event and its associated runoff, CGS downloaded rainfall and stream flow data from the SBC webpage (SBC, 2023). CGS focused on assessing the rainfall rates within basins that drain into Montecito along Montecito Creek and San Ysidro Creek, collecting data from two rain gages, one at the mountain front (Cold Springs Gage, Figure 2a) and one at the top of the basin (East Camino Cielo Gage, Figure 2b).



Data: National Weather Service; Map: Erin Davis/Axios Visuals

Figure 1. Total rainfall distribution across California from December 24, 2022 to January 11, 2023.

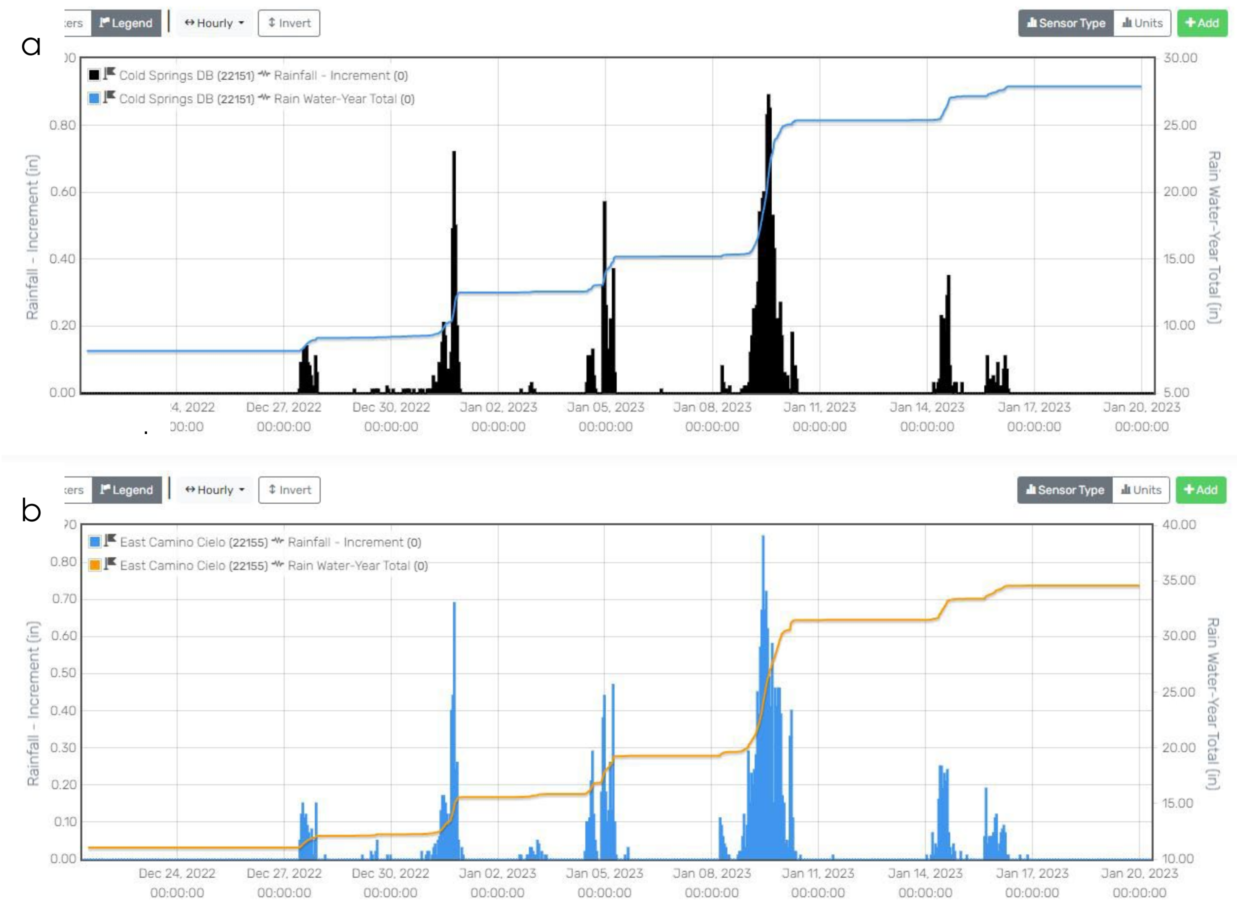


Figure 2. 1-hour incremental and cumulative rainfall data for Cold Springs DB (a, top) and East Camino Cielo (b, bottom) (Source: SBC, 2023)

After comparing the rainfall accumulations at the 0.25, 1, and 24 hour durations against data in Atlas 14, it appears the short duration rainfall ≤1 hour a was not extreme with annual return intervals (RIs) of <2 years; however, the longer duration rainfall at 24 hours increased in significance and had annual recurrence intervals of about 50 years at the mountain front and 30 years at the divide. A average of these RIs suggest the rainfall that triggered the runoff associated with the January 9, 2023, event in Montecito Creek and San Ysidro Creek had an RI of about 40 years.

Rain Gage	Duration (hours)	Rain Accumulation (inches)	RI based on NOAA Atlas 14* (years)
Cold Springs	0.25	0.28	1
	1	0.89	2
	24	9.00	54
East Camino Cielo	0.25	0.33	1
	1	0.87	1
	24	10.33	31

Table 1: January 9, 2023, Strom Rainfall Accumulations and Annual Recurrence Intervals (RI) *NOAA Atlas 14, Volume 6, Version 2: https://hdsc.nws.noaa.gov/

Peak 1-hour rainfall occurred in the basins above (north) Montecito at about 13:00 hours. Peak runoff was recorded in a downstream stream gage along Montecito Creek, operated by SBC (Montecito Creek Gage, Figure 3). According to available data, the peak flow in Montecito Creek was about 3,200 cubic feet per second (CFS) and occurred at 14:10:28, about 1-hour after peak rainfall occurred within the basin. After evaluating flood-frequency data from stream gages in the area, we estimate the peak flow had a clearwater equivalent RI of about 40-75 years. However, based on discussions with the County Hydrologist, Shawn Johnson, and recent hydrology and hydraulic modelling performed as part of an on-going FEMA floodplain assessment, which uses a much longer record of rainfall data to generate peak flow-frequency relationships, the estimated peak flow was more likely equivalent to a 25-year runoff event.

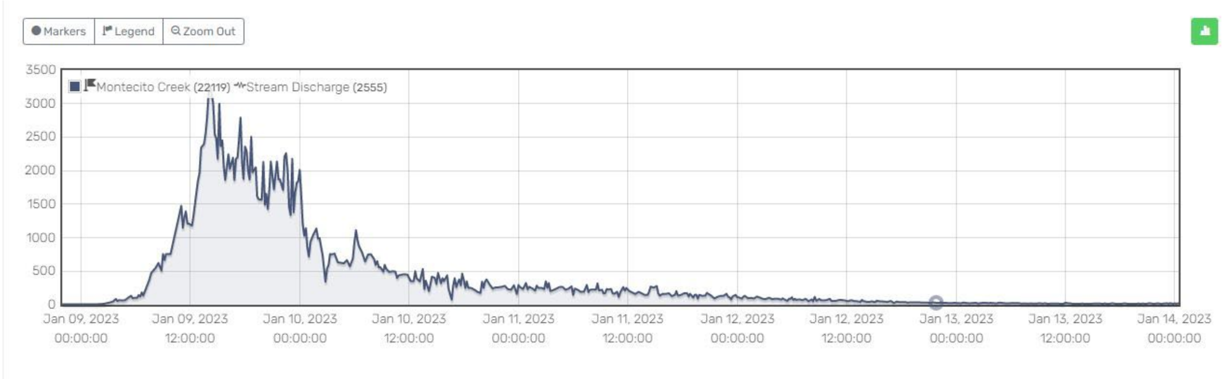


Figure 3. Discharge hydrograph from -9 event in Montecito Creek (SBC, 2023)

Based on the similarity in size and relief between the gaged Montecito Creek basin and the ungaged San Ysidro Basin to the east, we performed a simple flow transfer method to estimate peak flows in San Ysidro Creek. The method used the calculated flow per unit area in the gaged Montecito Creek and applied it to the area of the ungaged San Ysidro Creek. The results indicate the peak flow in San Ysidro Creek was about 2,300 cfs. Due to the complexities of measuring highly dynamic flows, rich in sediment and debris, we expect the reported flows, and associated RIs to be approximate and likely have large errors.

Observed Storm Related Impacts

The January 9, 2023 event and associated runoff triggered multiple landslides and generated debris-laden flows that transported large volumes of bedload that filled debris basins, plugged crossing structures, and infilled low-gradient channels. In low-gradient areas upslope of Highway 101, flows overtopped channel banks and caused localized flooding, forcing the closure of Highway 101.

Several small debris basins are positioned near the mountain front upslope of Montecito. These basins were constructed in the later 1960s and early 1970s to retain debris and reduce the threat of flood and debris flow hazards downgradient. In addition, six debris-flow nets were installed upstream of Montecito to mitigate against debris-flow hazards[1]. We visited a number of the debris basins and debris-flow nets and report on their status following the January 9, 2023, event (Figure 4, Appendix A). The results of our inspection

[1] https://www.tprcsb.org/nets

indicated that most of the basins and one of the debris-flow nets had been filled with debris before being overtopped.

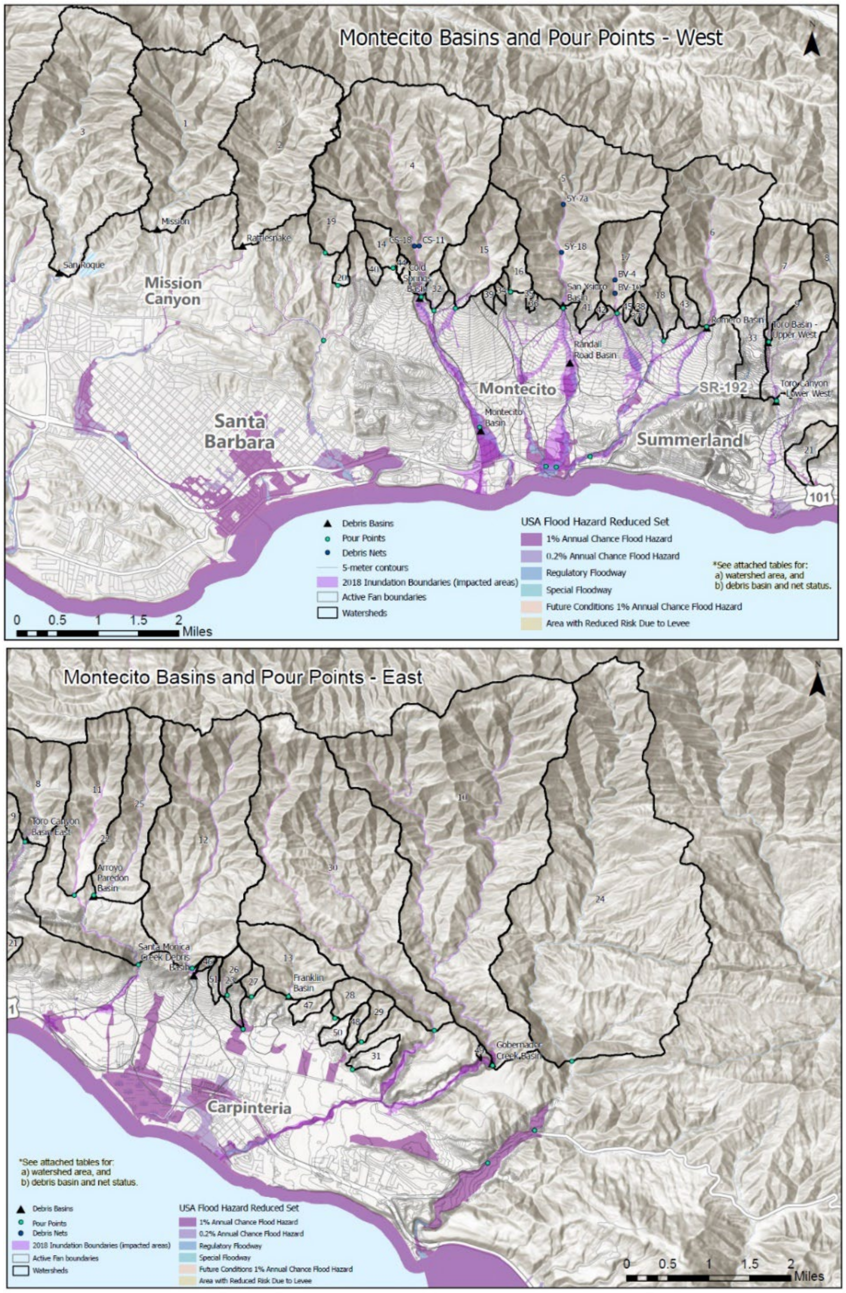


Figure 4. Maps showing the location of debris basins, debris-flow nets, relative to the mountain front and downstream communities of Santa Barbara and Montecito (top) and Carpinteria (bottom).

Based upon limited field review and rapid evaluation of post event aerial photography collected by the Civil Air Patrol, the primary source of debris mobilized along mainstem channels above Montecito (Cold Spring Canyon, Hot Springs Canyon, San Ysidro Canyon, and Romero Canyon) appears to have mostly originated within the channel through scour (incision) and bank slough, and to a somewhat lesser extent by landslide activity along tributary slopes immediately flanking the mainstem channels. Source areas high in the watersheds appear to have been impacted by shallow debris slides that transitioned into debris flows as they progressed downslope that undoubtedly contributed to re-loading the channels with colluvium (Figure 5).

The volume of landslide-generated sediment and sediment in scoured oversteepend channel banks stored high in the watersheds is unknown at this time; thus, the risk this sediment presents in subsequent storms is uncertain. Despite the uncertainty in volume of deposited landslide material and remaining sediment in oversteepend channel banks, field observations of stored material currently present within the channels suggest a high volume of material is readily available and could be mobilized during future high-discharge flows. More detailed information such as Lidar, high resolution georeferenced photography, and upslope field review would be required to refine the understanding of downstream risk more accurately.

Randall Road Debris Basin

Following the Thomas Fire and the January 9, 2018, debris flows, the community and Santa Barbara County pooled resources to purchase property and construct the Randall Road Debris Basin using FEMA and State grant funds. The Randall Road basin is upgradient of the intersection of State Route 192 and San Ysidro Creek This is the largest of the debris basins used to capture debris and reduce downstream impacts above Montecito. The Randall Road Basin is downstream of the smaller San Ysidro debris basin, both are along San Ysidro Creek. The Randall Road debris basin was designed to allow small stream flows to pass along a constructed channel capable of handling a 5-year RI flow. For larger flows, like the January 9, 2023, event, the basin was designed to capture logs and debris (sediment, cobbles, boulders) to mitigate hazards downgradient and help protect private property and critical public infrastructure, including Highway 101.

Figure 5. Representative photo of shallow landslides (arrow) that deliver sediment into upland swales and creeks.

Initial reports following the January 9, 2023, event indicated the San Ysidro debris basin was reported 100% full, and the Randall Road debris basin was reported approximately 40 to 50% full. Given the extent of debris loading and the loss of capacity, to mitigate flood and debris hazards during subsequent storms, Santa Barbara County requested assistance to remove debris from the Randall Road basin. As a result, CalOES mobilized the California Nation Guard and tasked them to remove the accumulated debris from Randall Road basin and re-establish the basin back to its pre-event condition. The CNG mobilized and arrived on-site on January 12, 2023, two days prior to a storm that was forecast to arrive on January 14, 2023.

CGS staff mobilized on January 13, 2023, met CNG and SBC representatives on site, and worked on developing an emergency response plan to ensure worker safety. The plan formulated and agreed by the CNG included setting up a direct line of communication with weather forecasters who monitored developing storms and with forward scouts positioned upstream to communicate changes in flow within San Ysidro Creek. Activation of the emergency action plan would begin if rainfall rates greater than about 0.6 inches an hour were measured at the Cold Springs gage, or if rapid rising stream

Figure 6. Photo of CNG actively excavating material from basin on January 14, 2023 (Top) and basin completely empty of debris and returned to near-previous conditions on January 23, 2023 (Bottom)

flow was observed; the on-site commander would then be notified, and equipment and personnel would stop operations and move to pre-identified safe areas positioned on high ground west of the basin. The CNG constructed a temporary berm along the creek to facilitate dry operations in the debris basin. The emergency plan included maintaining the integrity of the debris basin by ensuring that the temporary berm along the creek was capable of being breached to allow filling of the debris basin should a flood stage runoff event occur prior to completion of excavation.

Fortunately, the January 14, 2023, storm was small and the CNG were able to continuously perform excavation and off-haul operations 24 hours a day, starting on January 13, 2023, and continuing to January 23, 2023. During this period, approximately 15,000 cubic yards of material were removed, and the basin was returned to pre-event conditions (Figure 6). The work performed by the CNG was critical to protect downstream property, life, and natural resources.

Conclusion

In response to CalOES Mission Task #2023-SOC-89041, CGS worked with Santa Barbara County and the California National Guard to evaluate potential post-flood impacts, implement an emergency management plan for the removal of debris from the Randall Road debris basin, and provide technical assistance to the CNG. The work performed by the CNG in removing accumulated debris from Randall Road basin and returning the basin to its pre-storm conditions has helped mitigate potential flood and debris flow hazards to private property and public infrastructure downstream.

Please do not hesitate to contact us if you have any questions.

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1/27/2023

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Engineering Geologist

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1/27/2023

Donald N. Lindsay, CEG 2323, GE 3097

Sup. Engineering Geologist/Geotechnical Engineer

Attachments:

Appendix A: Summary Table and select photos of debris basin and debris-flow nets as of January 16, 2023.

References:

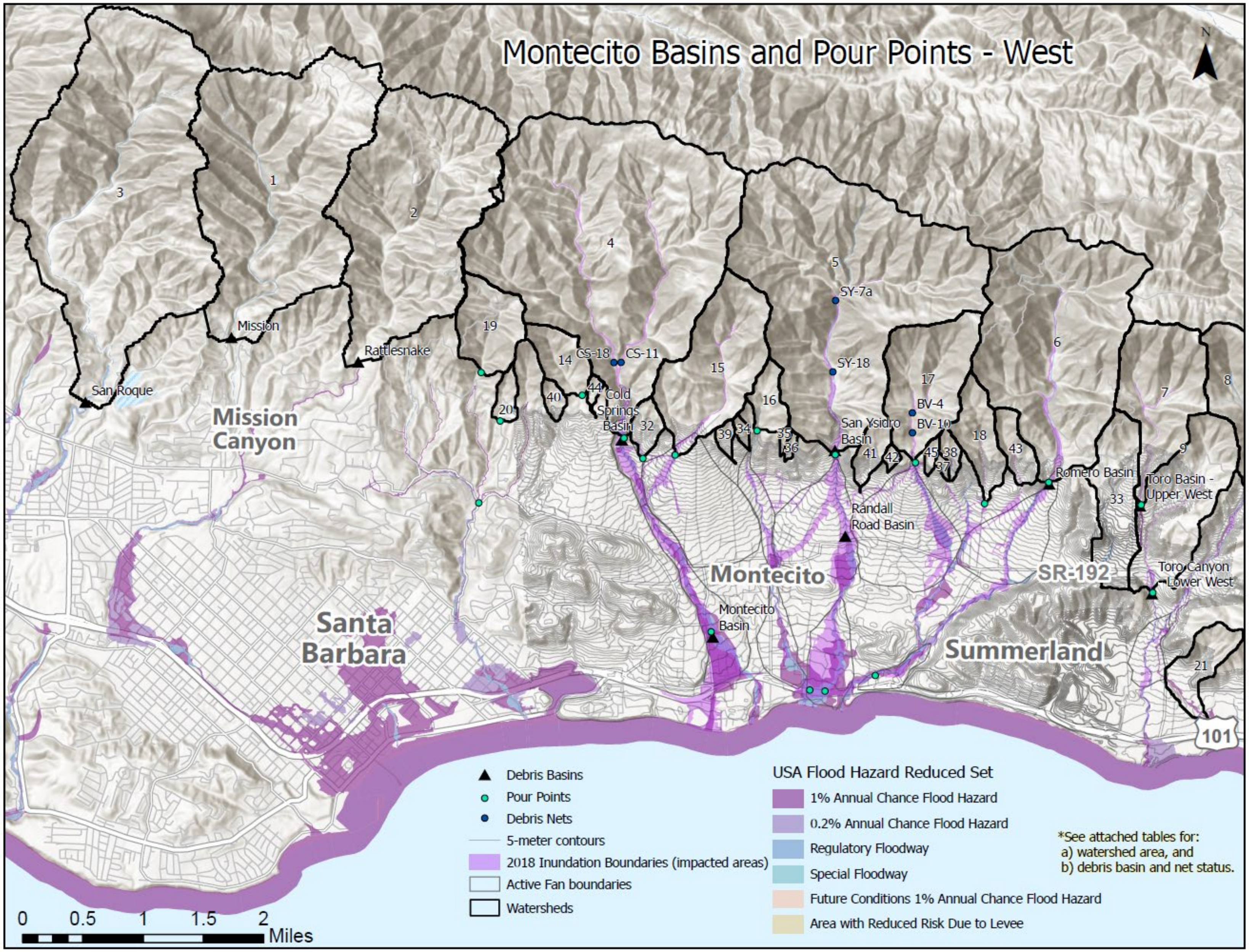
Gotvald, A.J., Barth, N.A., Veilleux, A.G., and Parrett, Charles, 2012, Methods for determining magnitude and frequency of floods in California, based on data through water year 2006: U.S. Geological Survey Scientific Investigation Report 2012-5113, 38 p., 1 pl. (http://pubs.usgs.gov/sir/2012/5113/)

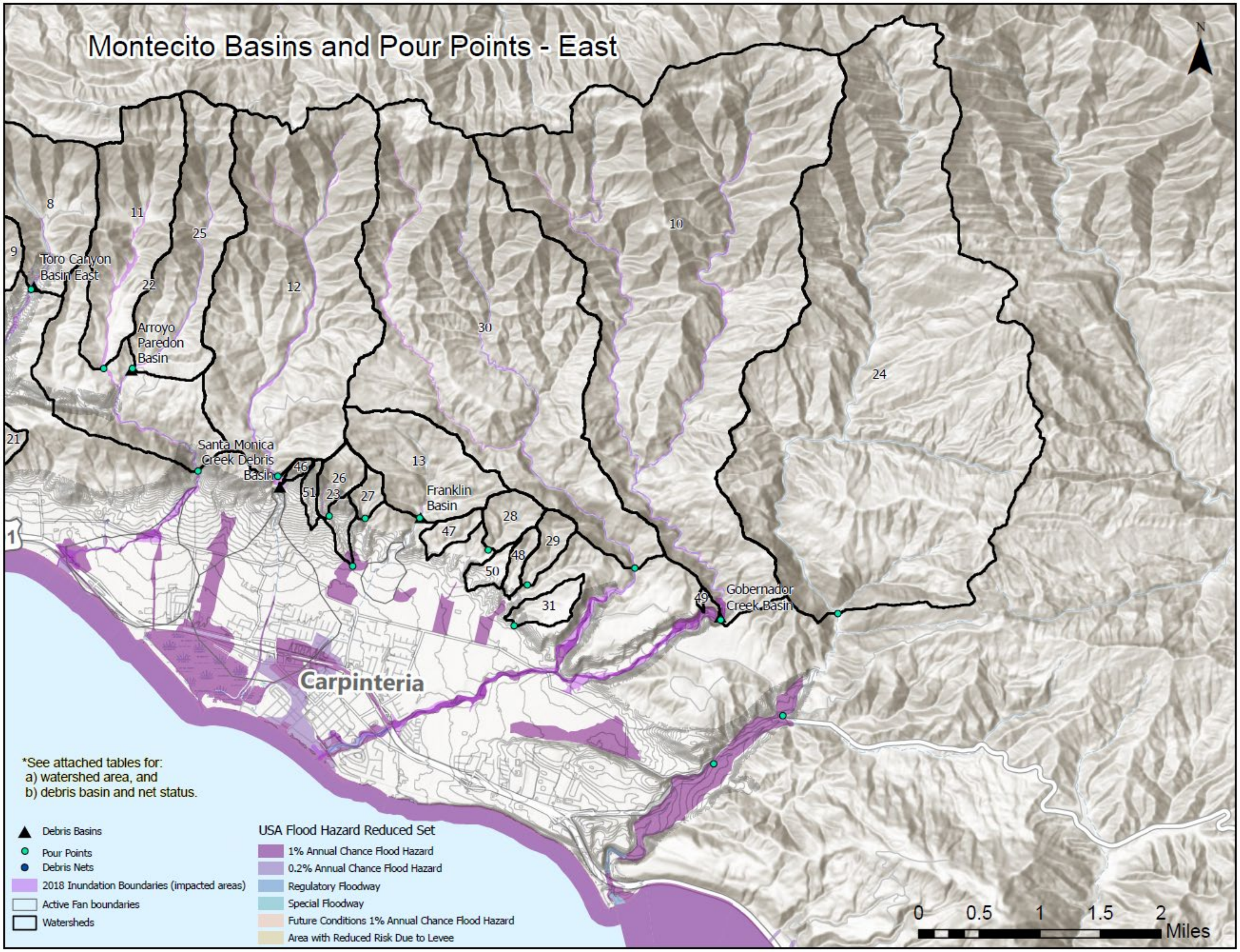
Santa Barbara County, 2023, raingage and flow data, available at: https://rain.cosbpw.net/

Appendix A

Summary table and photos of debris basins and debris-flow nets
(As of January 16, 2023)

Basin (West to East)	Rough occular estimate of % filled	Inlet Structure Status	Spillway Status	Active debris removal operations
Cold Springs	100	Clear/Partially functional	Clear/Functional	Active operations cleared inlet pipe and were removing sediment from basin.
Montecito	100	NA	Clear/Functional	Active excavation opened a trapezoidal channel along east side of basin to reestablish conveyance.
San Ysidro	100	Blocked	Clear/Functional	Active debris removal occurring
Randall Road	10	NA	NA	Active excavation opened a trapezoidal channel along east side of basin to reestablish conveyance.
Romero	30	Clear	Clear/Functional	None
Toro Basin Upper West	10	Clear	Clear/Functional	Active operations removing sediment from basin.
Toro Canyon Lower West	Not Inspected, no access.			
Toro Canyon East	20	Clear	Clear/Functional	None
Arroyo Pardon	15	Clear	Clear/Functional	Two excavators were unloading to proceed with excavation.
Santa Monica	40	Clear/functional	Clear/Functional	Lower most inlet may still be buried. Second inlet structure appeared functional. Uppermost inlet structure appeared functional. Equipment staged but not actively working to remove debris.
Gobernador	100	Clear	Clear/Functional	Evidence of recent debris removal from inlet structure.
San Roque	100	NA	Clear/Functional	None
Mission	25	Clear	Clear/Functional	None
Rattlesnake	20	Clear	Clear/Functional	None
Upper San Yisidro Canyon Debris Net	100	1-13-23 FIRIS		15,434 CY Capacity BOTH San Yisidro Nets
Lower San Yisidro Creek Debris Net	0	1-13-23 FIRIS		https://www.tprcsb.org/nets
Upper Cold Springs Debris Net	0	1-16-23 Don Lindsay		9,630 CY Capacity BOTH Cold Springs nets
Lower Cold Springs Debris Net	0	1-16-23 Don Lindsay		https://www.tprcsb.org/nets
Upper Buena Vista Debris Net	2	1-13-23 FIRIS		21,625 CY Capacity BOTH Buena Vista nets
Lower Buena Vista Debris Net	0	1-16-23 Don Lindsay		https://www.tprcsb.org/nets


Montecito Basins and Pour Points - West
N
3
1
2
4
5
6
7
8
9
San Roque
Mission
Rattlesnake
19
14
CS-18
CS-11
44
40
20
Cold Springs Basin
32
15
16
39
34
35
36
SY-7a
SY-18
San Ysidro Basin
41
42
17
BV-4
BV-10
45
38
37
18
43
Romero Basin
33
Toro Basin - Upper West
Toro Canyon Lower West
Randall Road Basin
Montecito Basin
Mission Canyon
Santa Barbara
Montecito
SR-192
Summerland
21
101
Debris Basins
Pour Points
Debris Nets
5-meter contours
2018 Inundation Boundaries (impacted areas)
Active Fan boundaries
Watersheds
USA Flood Hazard Reduced Set
1% Annual Chance Flood Hazard
0.2% Annual Chance Flood Hazard
Regulatory Floodway
Special Floodway
Future Conditions 1% Annual Chance Flood Hazard
Area with Reduced Risk Due to Levee
*See attached tables for:
a) watershed area, and
b) debris basin and net status.
0 0.5 1 1.5 2
Miles


Montecito Basins and Pour Points - East
8
11
25
9
Toro Canyon Basin East
22
12
10
30
24
Arroyo Paredon Basin
21
Santa Monica Creek Debris Basin
46
26
13
51
23
27
Franklin Basin
47
28
29
48
50
31
49
Gobernador Creek Basin
Carpinteria
*See attached tables for:
a) watershed area, and
b) debris basin and net status.
Debris Basins
Pour Points
Debris Nets
2018 Inundation Boundaries (impacted areas)
Active Fan boundaries
Watersheds
USA Flood Hazard Reduced Set
1% Annual Chance Flood Hazard
0.2% Annual Chance Flood Hazard
Regulatory Floodway
Special Floodway
Future Conditions 1% Annual Chance Flood Hazard
Area with Reduced Risk Due to Levee
0
0.5
1
1.5
2
Miles

San Roque

Mission

Rattlesnake

Cold Springs

Montecito

San Ysidro

Randall Road

Romero

Toro East

Upper Toro West

Arroyo Paredon

Santa Monica

	
Gobernador	*Image of Upper Debris Flow net in San Ysidro Canyon (FIRIS, 2023)*