Burned Area Emergency Response (BAER) Assessment
FINAL Specialist Report – GEOLOGIC HAZARDS

Holy Fire, Cleveland N.F.

August 27, 2018

Jonathan Yonni Schwartz – Geomorphologist/Geologist, Los Padres NF
Tori Stempniewicz –Hydrologist, Cleveland NF

Introduction

The Holy Fire started on August 06, 2018, about a ¼ mile east-northeast from the confluence of the Trabuco Canyon and the Holy Jim Canyon, on the Trabuco Ranger District of the Cleveland National Forest. The Holy Fire burned a total of 22,877 acres, out of which 18,003 acres burned on National Forest lands, 2,448 acres burned on non FS lands inside the congressional boundary of the Cleveland NF and 2,426 acres burned off National Forest lands. Out of a total of 22,877 acres, 3,290 acres were high soil burn severity (14%), 16,258 acres were moderate soil burn severity (71%), 1,780 acres were low soil burn severity (8%) and 1,549 acres were very low soil burn severity or unburned (7%). The unburned acres refer to unburned areas within the fire perimeter. This report describes and assesses the increase in risk from geologic hazards within the Holy Fire burned area.

When evaluating Geologic Hazards, the focus of the "Geology" function on a BAER Team is on identifying the geologic conditions and geomorphic processes that have helped shape and alter the watersheds and landscapes, and assessing the impacts from the fire on those conditions and processes that potentially could affect downstream values at risk. The fire removed vegetation that helps keep slopes and drainages intact, changed the structure and erosiveness of the soil, and altered the stability of the landscape. Using the understanding of rock types and characteristics, geomorphic processes, and distribution of geologic hazards helps predict how the watersheds will be impacted during upcoming storm seasons. Within the Holy Fire burned area, some slope failures such as rock fall, debris slides and dry ravel activities have occurred in the past and will increase during future storms.

Wildfire can significantly alter the hydrologic response of a watershed to the extent that even modest rainstorms can produce dangerous debris flows, rock falls and debris slides. Debris flows and rock falls are the primary geologic hazards associated with burned watersheds (Santi et al., 2013; Parise and Cannon, 2012). Watersheds with steep slopes and significant amounts of moderate to high soil burn severity are especially likely to generate debris flows. The majority of debris flows exacerbated by wildfires usually occur within 1-3 years after the watershed's burned. Fast moving, highly destructive debris flows triggered by intense rainfall are one of the most dangerous post-fire hazards. As a result of fires, protective vegetation is gone or altered and will

not return to the same levels of protection for years. Soil is exposed and has become weakened, and surface rock on slopes has lost its supporting vegetation. Slopes will experience greatly increased erosion. Stream channels and mountainside ephemeral channels will be flushed of the sediment that in some places is loose and deep, in other places shallow. That sediment will deposit in some channels, choking flow, raising flood levels and covering roads with deep sediments. Risk to human life, infrastructure and natural resources are high in some areas.

I. Resource Setting

Geology and Geomorphology: The Holy Fire occurred on the Santa Ana Mountain range, the western-most of three major fault blocks that make up the Peninsular Ranges Geologic Province. The Santa Ana Mountain block is bounded by the Elsinore fault zone to the east, Christianitos Fault zone to the west, terminating sharply at the Whitter Fault to the north, and grading down to the Santa Rosa Plateau Ecological Preserve to the south (Fig. 1). The ridgeline of this range approximately co-located with the county line between Orange County to the west and Riverside County to the east.

The Elsinore Fault zone is a large right-lateral strike-slip fault structure part of the San Andreas Fault system. Elsinore is slipping at approximately 4.0 mm/yr, and has historically produced earthquakes with magnitudes 5-7 (CalTech, 2013).

Upper Cretaceous and Cenozoic sedimentary rocks ranging in age from Upper Cretaceous through Holocene are exposed over most of the western part of the Santa Ana block (Morton and Miller, 2006). The eastern part of the block is a basement assemblage of Mesozoic metasedimentary and Cretaceous volcanic and batholithic rocks. The northern part of the Santa Ana Mountains is a complexly faulted anticlinal structure. Overlaying this basement is a thick section of upper Cretaceous, chiefly marine rocks, and Paleogene marine and nonmarine rocks. The **geology** of the Holy Fire burn area (Fig. 2) is underlain predominantly by Jurassic-aged Bedford Canyon formation, a slightly metamorphosed assemblage of marine sediments, and Cretaceous-aged heterogeneous granitic formations. A few small areas of the foothills on the eastern side of the burn are part of the Perris block, a relatively undeformed, low relief area underlain by prebatholithic metasedimentary rocks intruded by Cretaceous plutons.

Structurally, the northern part of the Santa Ana Mountains is a northwest-plunging complexly faulted anticline where upper Cretaceous and Tertiary rocks rest on older Cretaceous volcanic and plutonic rocks and Jurassic metasedimentary rocks. This anticlinal structure is asymmetrical with a gentler sloping westward flank and an abrupt east flank along the Elsinore Fault Zone.

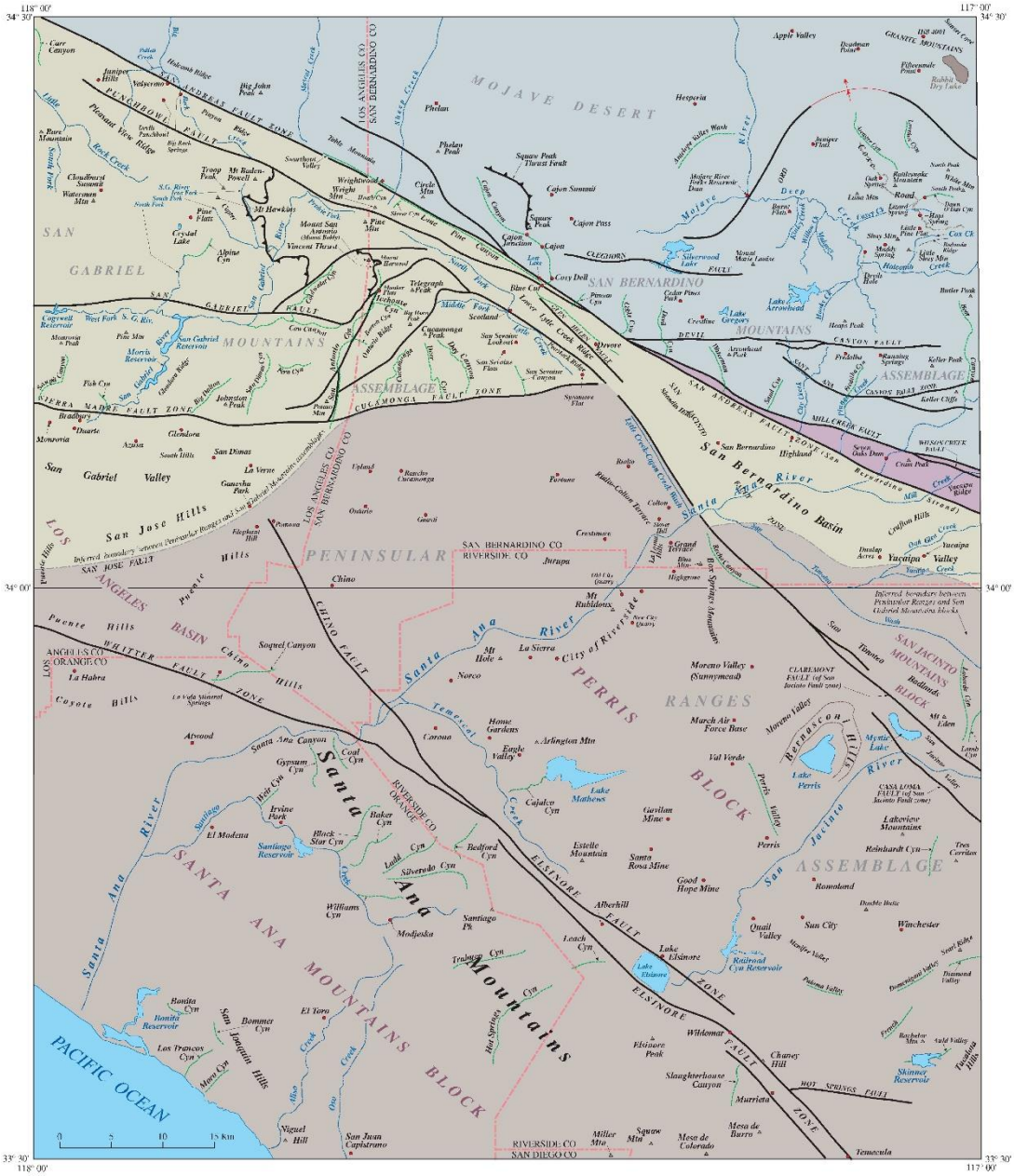


Figure 1. Map of San Bernardino and Santa Ana 30' x 60' quadrangles showing place names used in DESCRIPTION OF MAP UNITS and geologic report. Colored areas define structural assemblages. Approximate locations of most faults having large displacements or lengths are shown. Inferred boundary between Peninsular Ranges and San Gabriel Mountains assemblages is hidden beneath thick Quaternary deposits, and its location and character are highly speculative. ▪ Town or geographic feature; ▲ Mountain Peak.

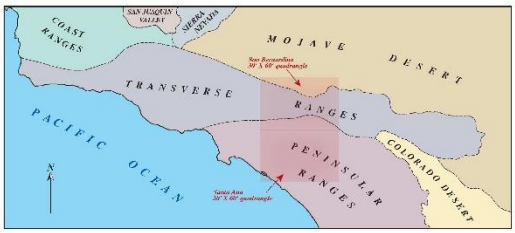
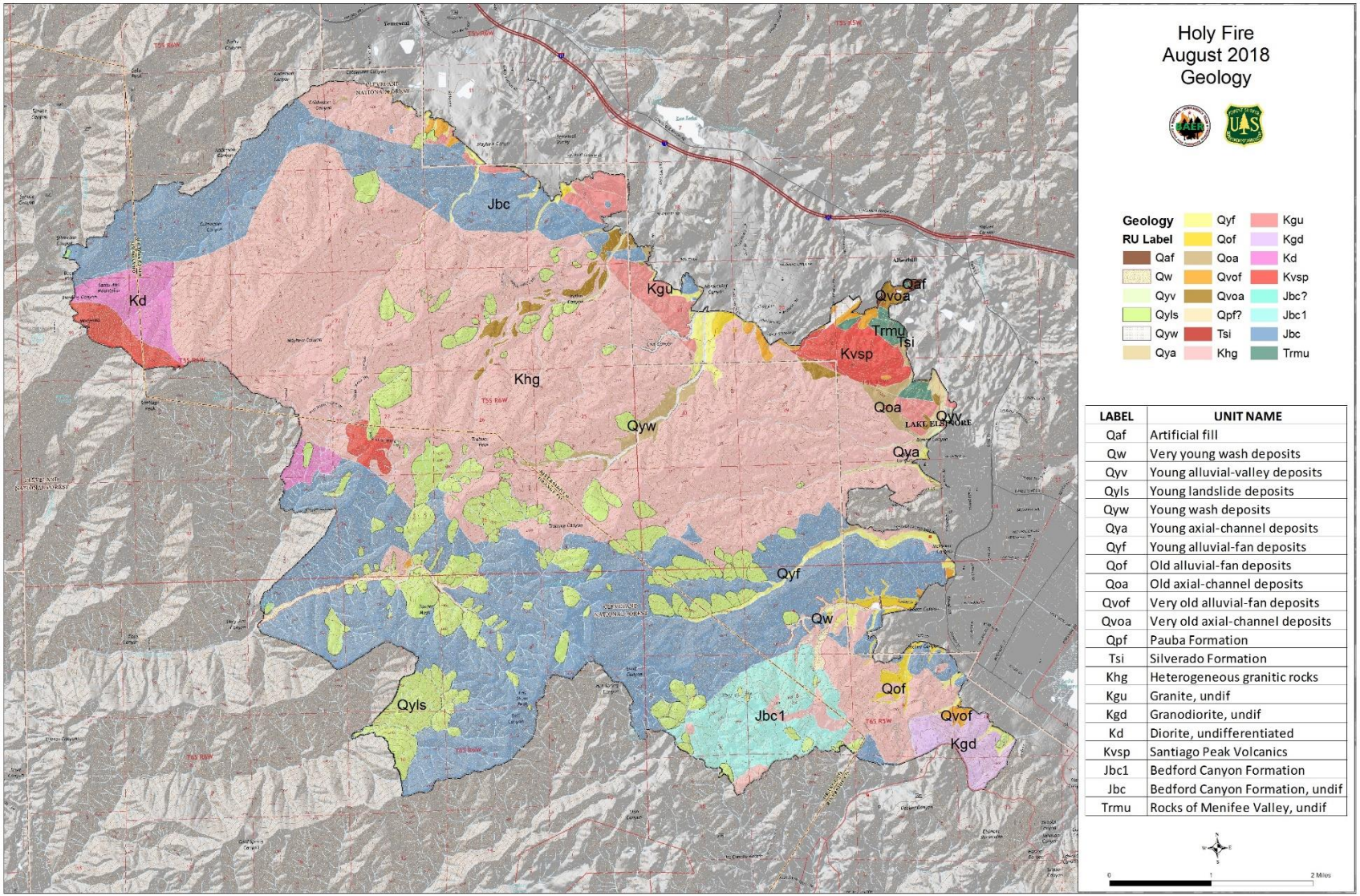


Figure 2. Map showing San Bernardino and Santa Ana 30' x 60' quadrangles in relation to physiographic provinces in southern California. Within the quadrangles, provinces and provinces boundaries do not conform to the rock assemblages designated in the geologic report, DESCRIPTION OF MAP UNITS, and CORRELATION OF MAP UNITS.

<u>Figure 1</u> – Regional map of fault blocks of the Peninsular Ranges (Morton and Miller, 2006)



<u>Figure 2</u> – Geologic map of the Holy Fire burn area (Morton and Miller, 2006)

LABEL	UNIT NAME	DESCRIPTION
Qaf	Artificial fill	(late Holocene) Sand, gravel, and bedrock from pits, quarries, and excavations related to construction, mining, or quarrying activities
Qw	Very young wash deposits	(late Holocene) Unconsolidated sand and gravel deposits in active washes, ephemeral river channels of axial-valley streams, and in channels on active surfaces of alluvial fans; has fresh flood scours and channel-and-bar morphology.
Qyv	Young alluvial-valley deposits	(Holocene and late Pleistocene) Fluvial deposits along valley floors. Consists of sand, silt, and clay-bearing alluvium.
Qyls	Young landslide deposits	(Holocene and late Pleistocene) Slope-failure deposits that consist of displaced bedrock blocks and/or chaoticlaly mixed rubble. Slightly dissected or modified surfaces. Deposits may or may not be active under current range of climatic conditions. Found as concentrated, multiple slides in steep areas of highly fractured rocks.
Qyw	Young wash deposits	(Holocene and late Pleistocene) Unconsolidated to slightly consolidated sand and gravel deposits in marginal parts of active and recently active washes and ephemeral channels of axial-valley streams. Sediment derived from local bedrock or reworked from local, older Quaternary deposits.
Qya	Young axial-channel deposits	(Holocene and late Pleistocene) Slightly to moderately consolidated silt, sand, and gravel deposits.
Qyf	Young alluvial-fan deposits	(Holocene and late Pleistocene) Unconsolidated to moderately consolidated silt, sand, pebbly cobbly sand, and bouldery alluvial-fan deposits having slighlty to moderately dissected surfaces.
Qof	Old alluvial-fan deposits	(late to middle Pleistocene) Moderately-to-well-consolidated silt, sand, and gravel.
Qoa	Old axial-channel deposits	(late to middle Pleistocene) Moderately-to-well-consolidated silt, sand, and gravel having moderate to well developed pedogenic soils.
Qvof	Very old alluvial-fan deposits	(Middle to early Pleistocene) Moderately-to-well-consolidated silt, sand, gravel, and conglomerate. In much of Peninsular Ranges area, unit is moderately well consolicated orangish brown sand and silt that is typically well dissected.
Qvoa	Very old axial-channel deposits	(Middle to early Pleistocene) Moderately-to-well-consolidated silt, sand, gravel, and conglomerate. In much of Peninsular Ranges area, unit is moderately well consolicated orangish brown sand and silt that is typically well dissected.
Qpf	Pauba Formation	(Pleistocene) Siltstone, sandstone, and conglomerate. Named by Mann (1955) for exposures in Rancho Pauba area about 3.2 km southeast of Temecula.
Tsi	Silverado Formation	(Paleocene) Nonmarine and marine sandstone, siltstone, and conglomerate. Basal conglomerate overlain by relatively thin sequence of sandstone and siltstone. Distinctive Claymont clay bed overlies sandstone and siltstone sequence, and is overlain by a thick sequence of sandstone, siltstone, and conglomerate that includes a second clay bed, known as Serrano clay bed.
Khg	Heterogeneous granitic rocks	(Cretaceous) A wide variety of heterogeneous grantitic rocks occur in Santa Ana quadrangle, mostly composed of a mixture of monzogranite, granodiorite, tonalite, and gabbro. Within the Santa Ana mountains, tonalitic compositions are most abundant.
Kgu	Granite, undif	(Cretaceous) Leucocratic fine to coarse grained massive granite and biotite monzogranite. Most is equigranular and consists of quartz and alkali feldspars.
Kgd	Granodiorite, undif	(Cretaceous) Biotite and hornblende-biotite granodiorite, undifferentiated. Most is massive and medium grained.
Kd	Diorite, undifferentiated	(Cretaceous) Mostly fine- to medium-grained, massive, dark gray to black hornblende diorite.
Kvsp	Santiago Peak Volcanics	(Cretaceous) Basaltic andesite, dacite, rhyolite, volcaniclastic breccia, welded ruff, and epiclastic rocks.
Jbc1	Bedford Canyon Formation	(Jurassic) Southern part consists of brown-weathering, massive-appearing quartz-rich metasandstone and impure quartzite. Locally has thin-layered fine grained sandy intervals, discontinuous small folds (6 to 8 cm), and abundant fine-grained disseminated pyrite.
Jbc	Bedford Canyon Formation, undif	(Jurassic) Slightly metamorphosed assemblage of interlayered argillite, slate, phyllite, graywacke, impure quartzite, and small masses of limestone. Bedding and primary sedimentary structures are commonly preserved, althought tightly folded bedding is common. Fissile, black argillite and slate and very fine-grained and consist of beds 2 to 8 cm in thickness. Massive bedded, impure, fine-to medium-grained, pale-gray to pale-brown quartzite and graywacke beds are 4 to 30 cm thick. Locally carbonaceous. Lenses of conglomerate occur sparsely through sequence.
Trmu	Rocks of Menifee Valley, undif	(Triassic) Wide variety of low-to high-grade metamorphic rocks. Most places unit contains biotite schist; some low-grade rocks have primary sedimentary structures.

<u>Figure 3</u> – Geologic unit descriptions (Morton and Miller, 2006)

In this area, various forms of land-sliding, rock-fall, debris flows and erosion are frequent events in the steep, geologically young mountains, and occur naturally even without the effects of fires. Fires can dramatically increase slope instability. Instability features associated with this area include rock fall, landslides, and debris flows which threaten wildlife, human life, can damage and destroy homes, businesses, and other infrastructure, block or carve out sections of roads, sever pipelines and other utilities, block stream channels, add large quantities of sediment to stream channels and water bodies, and disrupt the livelihood of workers and communities.

The Peninsular Ranges geomorphic Province extends over 1,400 km (870 mi) from just south of the San Gabriel and Santa Monica mountains into Mexico, forming the Baja California peninsula. The province extends to the west offshore to the continental margin, and bounded to the east by the west side of the Salton Trough. Structural features and overall physiographic features are oriented northwest, parallel to the Pacific coastline. The physiography of the region and the area burned by the Holy Fire is dominated by extremely rugged slopes, draining into Lake Elsinore and Temescal Wash to the east, a north-flowing tributary of the Santa Ana River, and flowing through Orange County to the Pacific Ocean to the west.

The Santa Ana Mountains consist of three topographically distinct segments, all three bounded on the east by a steep escarpment along the Elsinore Fault Zone. The northern segment extends southward to the north end of Lake Elsinore at Leach Canyon where there is a distinct jog in the mountain front. The east flank of the mountains is deeply dissected and the crest of the range is at elevations of 1,200 to 1,700 m (3,940 to 5,580 ft). Drainages extend four to six km (2.5 to 3.7 mi) into the mountains from the eastern margin. Most drainages on the west side of the mountains are southwest flowing and extensively developed. Deeply dissected sedimentary rocks flank the west side of the Santa Ana Mountains, where a thick section of Upper Cretaceous sedimentary rocks rest on crystalline basement.

Fire removes vegetation and alters water infiltration characteristics, which play a key role in holding soil on the slope surface. The more intense the burn, the more severe the consequence to the soil structure and ground cover, especially on these old, dense stands of thick vegetation which have not burned for many years.

Consequently, the steepest areas, with the most highly fractured or decomposed rock and the thickest accumulation of unconsolidated soil, which were subjected to the most severe burn are now at the highest risk from **debris slides, debris flows, rock-fall, and slumping**.

Following wildfire, many factors combine to influence the **stability of slopes** in this area:

- Steepness and configuration of slopes

- Degree of fracturing and/or weathering of rock units, relative to the rate of soil/colluvial material formation and rock strength/competence
- Degree of severity of the burn, relative to destruction of slope cover and alteration of soil properties
- Amount, intensity and duration of precipitation and runoff, and flooding
- Degree of slope saturation and groundwater level
- Intensity and duration of seismic shaking, especially when slopes are saturated
- Alteration of natural slope stability by excavations such as roads
- Angle and direction of dip or inclination of strata, particularly when a less stable rock mass, often shale or claystone, becomes saturated above a steeply dipping resistant layer, such as sandstone
- Undercutting of slopes and channels by stream action and gullying

Just as other BAER assessments have revealed, assessment of the Holy Fire shows that susceptibility to slope instability is associated with watersheds within the fire that have significant volumes of sediment in the channels or are likely to experience increases in sediment volume from fire-affected slopes. Sediment increase is associated with significant areas of susceptible bedrock that were subjected to high or moderate burn severity. The basis for this assumption originates from studies of wildfire-generated debris flows, which can be extrapolated to other types of slope movement. Rather than being the result of infiltration-induced slope movements into the channels, wildfire-generated debris flows are a result of progressive bulking of storm flow with sediment within the channel and washed from the adjacent slopes (Cannon, 2000, 2001). As Cannon and others (2003) state:

"Wildfire can have profound effects on a watershed. Consumption of the rainfall-intercepting canopy and of the soil-mantling litter and duff, intensive drying of the soil, combustion of soil-binding organic matter, and the enhancement or formation of water-repellent soils can result in decreased rainfall infiltration into the soil and subsequent significantly increased overland flow and runoff in channels. Removal of obstructions to flow (e.g. live and downed timber, plant stems, etc.) by wildfire can enhance the erosive power of overland flow, resulting in accelerated stripping of material from hillslopes. Increased runoff can also erode significant volumes of material from channels. The net result of rainfall on burned basins is often the transport and deposition of large volumes of sediment, both within and down-channel from the burned area."

Destructive debris flows bring side-slope materials and channel deposits racing down channel bottoms in a slurry similar to the consistency of concrete, in masses from a few hundred cubic yards to hundreds of thousands of cubic yards of saturated material.

A key aspect that makes debris flows important is well described by Cannon and others (2003) in their documentation for debris flow hazard maps prepared for the Piru, Simi, and Verdale wildfires of 2003:

"Debris flows pose a hazard distinct from other sediment-laden flows because of their unique destructive power. They can occur with little warning, can exert great impulsive loads on objects in their paths, and even small debris flows can strip vegetation, block drainage ways, damage structures, and endanger human life."

USGS Debris Flow Assessment:

In order to assess the probability and potential volumes of debris flows in the burned area the assistance of the US Geological Survey (USGS) - Landslide Hazards Program was obtained. Their ongoing research has developed empirical models for forecasting the probability and the likely volume of such debris flow events. To run their models, the USGS uses geospatial data related to basin morphometry, burn severity, soil properties, and rainfall characteristics to estimate the probability and volume of debris flows that may occur in response to a design storm (Staley, 2016). Estimates of probability, volume, and combined hazard are based upon a design storm with a peak 15-minute rainfall intensity of 12 – 40 millimeters per hour (mm/h) rate. After receiving the final Holy Fire burn severity map, the USGS conducted a debris flow assessment of the fire area that presented debris flow hazard classes, probability of occurrence, and volumes of materials occurring for multiple precipitation events.

We selected a design storm of a peak 15-minute rainfall intensity of 24 millimeters per hour (mm/h) rate to evaluate debris flow potential and volumes since this magnitude of storm seems likely to occur in any given year (Figures 7-9).

Debris flow probability and volume were estimated for each basin in the burned area as well as along the upstream drainage networks, where the contributing area is greater than or equal to 0.02 km^2, with the maximum basin size of 8 km^2.

The **probability model** was designed to predict the probability of debris-flow occurrence at a point along the drainage network in response to a given storm. Probabilities predicted by the model potentially range from 0 (least likely) to 100 percent (most likely). The predicted probabilities are assigned to 1 of 5 equal (20 percent) interval classes for cartographic display.

The **volume model** was designed to estimate the volume (in m^3) of material that could issue from a point along the drainage network in response to a storm of a given rainfall magnitude and intensity. Volume estimates were classified in order of magnitude scale ranges 0–1,000 m^3; 1,000–10,000 m^3; 10,000–100,000 m^3; and greater than 100,000 m^3 for cartographic display.

Debris-flow hazards from a given basin can be considered as the combination of both probability and volume. For example, in a given setting, the most hazardous basins will show both a high probability of occurrence and a large estimated volume of material. Slightly less hazardous would be basins that show a combination of either relatively low probabilities and larger volume estimates or high probabilities and smaller volume estimates. The lowest relative hazard would be for basins that show both low probabilities and the smallest volumes.

Kean et al. (2013) and Staley et al. (2016) have identified that rainfall intensities measured over durations of 60 minutes or less are best correlated with debris-flow initiation. It is important to emphasize that local data (such as debris supply) influence both the probability and volume of debris flows. Unfortunately, local specific data are not presently available at the spatial scale of the post-fire debris-flow hazard assessment done by the USGS. As such, local conditions that are not constrained by the model may serve to dramatically increase or decrease the probability and (or) volume of a debris flow at a basin outlet.

Findings / Observations

During ground surveys, a flight recon, and study of aerial photography, evidence of some past mass wasting, debris slide, rock-fall and debris flow deposits were observed throughout the burned area. From a flight recon and on-the-ground observations it is clear that a majority of the slopes and drainages in the Holy Fire are loaded with unsorted, unconsolidated materials available to be transported. Depending on the parent material / geological unit, some slopes and drainages are loaded with a thick layer of sediment only, while other slopes and drainages are loaded with unsorted / unconsolidated materials which include rocks of all sizes and sediments.

The Holy Fire burned area is divided by the Santa Ana Mountain Range ridge-line following a southeast – northwest direction. On the east side of the burned area, the landscape increases in elevation from the east (Temescal Valley) to west (Main Divide ridge-line / Santa Ana Mountain Range), from an elevation of about 1,200 feet above sea level (along Temescal Valley) to an elevation of about 4,600 feet above sea level at the top of the ridge-line, in the burned area (Trabuco Peak). The west side of the burned area drops down from the Main Divide ridge-line to the west boundary of the fire, from about 3,000 feet to about 1,600 feet above sea level at the confluence of Trabuco Canyon and Holy Jim Canyon (Figure 5).

On the east side of the burn area (east slopes of Santa Ana Mountain range), the burned area is drained by nine (9) major drainages all flowing from west – southwest to east – northeast into Temescal Wash, a tributary to the Santa Ana River. These drainages (from south to north) include: Dickey Canyon, Leach Canyon, McVicker Canyon, Rice Canyon, Bishop Canyon, Horsethief & Cow Canyons, Indian Canyon, Mayhew Canyon and Coldwater Canyon. South of Dickey Canyon

are a few small un-named drainages that are in the burn area and flow directly into some of the neighborhoods of Lake Elsinore (Figure 4).

On the west side of the burned area there are three (3) major drainages including (from north to south) Holy Jim Canyon, Trabuco Canyon and Bell Canyon, all flowing south-west through Orange County ending in the Pacific Ocean by Dana Point. At the southwest of the burned area are a few small un-named drainages.

Following are our findings and observations of each one of the burned drainages starting from the south-east to the north-east and back to the west side of the burned area:

Un-named drainages east of Dickey Canyon:

At the south-east end of the burn area are located a few un-named drainages, all of which drain right into neighborhoods of the city of Lake Elsinore. Lake View road is located along the mouth of these drainages. Most of these neighborhoods are built on alluvial fans and at the mouth of each of these drainages are debris flow deposits which, in many cases, extend into the neighborhoods (Photo 1, 2). Based on the soil burn severity, the steep burned slopes, and evidence of past debris flows and flooding, it is highly probable that some houses and streets in these neighborhoods will experience flooding, excessive sedimentation and might be impacted by debris flows (Figures 5, 6).

Photo 1 – Debris flow deposit at the mouth of unnamed drainage above Lakeview Dr.

These drainages are underlain by heterogeneous granitic rocks, primarily granodiorite, massive and medium grained. Drainage mouths have alluvial fan deposits (early Pleistocene through Holocene) and some young landslide deposits (late Pleistocene to Holocene).

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows discharging out of these few un-named drainages range from 20-40% in some cases and 40-60% in other cases (Figure 7). Some of the higher elevation branches of these drainages do have higher (60-80%) probabilities of producing debris flows. The volumes of predicted debris flows discharging out of these few un-named drainages range from 1K-10K cubic meters with a moderate combined hazard (Figures 8-9)

Photo 2 – Steep slopes of unnamed drainages above Lake Elsinore neighborhoods.

Dickey Canyon:

In comparison to other drainages in the burn area, Dickey Canyon is relatively small, but out of a total drainage area of 298 acres, 290 acres burned, resulting in mostly moderate soil burn severity. At the mouth of the canyon, the main drainage of Dickey Canyon is restricted by a concrete channel that flows under Toft Drive (Photo 3). The channel crosses under the street through an arch concrete culvert, about 10 feet long and 4 feet high (Photo 4). Based on the steep slopes, the soil burn severity, the large amounts of unconsolidated rocky materials in the upper drainage, and evidence of debris flow deposits at the mouth of the canyon, it is probable that debris flowing down the concrete channel will plug the arch culvert and overflow onto Toft Drive, impacting parts of the neighborhoods below.

The Dickey Canyon watershed is underlain by mostly Cretaceous-aged, heterogeneous, massive granitic rocks, with small slivers of Jurassic metasediments in the headwaters and near the canyon mouth. The valley floors in the lower half of the watershed have significant extents of old alluvial fan deposits (late to middle Pleistocene.

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows discharging out of Dickey Canyon are 40-60% in the main stem and 60-80% in some of the upper segments of the drainage. The volumes of predicted debris flow along the main channel of Dickey Canyon range from 1K-10K cubic meters with a moderate combined hazard.

Leach Canyon:

Leach Canyon drainage encompasses an area of 1,251 acres, out of which 1,216 acres burned, with a majority of them experiencing a moderate soil burn severity. This drainage also drains into neighborhoods of Lake Elsinore. Just above the crossing of the Leach Canyon channel and Grand Ave is the confluence of Dickey Canyon and Leach Canyon.

Leach Canyon is underlain by Jurassic aged, slightly metamorphosed sediments. The channel has formed along NE-SW trending faults that mark the transition from the steeper, more rugged northern topographic segment of the Santa Ana Mountains to the more subdued southern topographic segment (Morton and Miller, 2006). The southeastern corner of the watershed is underlain by heterogeneous granitics, and the channel has extensive wash deposits and alluvial fan deposits, ranging in age from late Pleistocene to Holocene.

Photo 3 – Concrete channel flowing from Dickey Canyon under Toft Dr.

Photo 4 – Dickey Canyon channel arch culvert crossing at Toft Dr.

At the road crossing, the Leach Canyon main channel crosses under Grand Ave via three box concrete culverts, each about 6 feet long and 3-4 feet high. About 2/3 of a mile above Grand Ave is located the Leach Canyon debris basin with a capacity of 165,000 cubic yards (126,150 cubic meters), managed by the Riverside County Flood Control District (Photo 5). In the event that flooding and debris over-tops the retention dam, the 3 culverts might get clogged, resulting in flooding and debris bypassing the culverts onto Grand Ave, flowing into and impacting the neighborhoods below. Based on past complaints of flooding presented in the Riverside County Flood Control District website, it is obvious that numerous properties in the neighborhoods below the Leach Canyon debris basin have experienced flooding in the past and most likely will experience flooding in future storms now that the drainage has burned.

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows discharging out of Leach Canyon are 60-80% in the main stem and 80-100% in some of the higher segments of the drainage. A few of the lower side drainages flowing into the main stem of Leach Canyon do present lower probabilities of 20-40% in some cases and 40-60% in other cases. The volumes of predicted debris flow along the main channel of Leach Canyon range from 10K-100K cubic meters in the lower main channel and 1K-10K cubic meters in some of the higher segments of the drainage. Combined hazard in the lower segment of Leach Canyon is presented as high.

Photo 5 – Debris basin in Leach Canyon.

McVicker Canyon:

The total area of the McVicker Canyon drainage is 1,497 acres out of which 1,450 acres burned mostly experiencing a moderate soil burn severity with some smaller areas at the top of the watershed that did experience high soil burn severity.

McVicker Canyon is underlain by Jurassic aged, slightly metamorphosed sediments. Young landslide deposits (Holocene and late Pleistocene) have been mapped extensively in the upper half of the watershed, emanating from steep hillslopes down into the channels. The valley bottom is filled with young alluvial fan deposits (Holocene and late Pleistocene) and old axial channel deposits (late to middle Pleistocene) on the margins in the lowest part of the watershed. The northern ridge of the watershed has heterogeneous Cretaceous granitic units.

About ½ a mile above Grand Ave is the McVicker Canyon debris basin (Photo 6). This basin has a capacity of 250,000 cubic yards (191,140 cubic meters). In the middle of the retention dam is a concrete spill-way flowing into a concrete channel which bypasses a Fire Station and the McVicker city park. The width of the concrete channel is about 12 feet and the height is about 12-15 feet. This concrete channel leads to a concrete box culvert crossing under Grand Ave (Photo 7). The dimensions of this culvert are about 12 feet wide by 10 feet high. Above Grand Ave and along the canyon are located some neighborhoods which are situated high above the channel bed, safe from any flooding which might occur in the main channel.

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows occurring along the main channel of McVicker Canyon are relatively high, ranging from 60-80%, while some segments along the higher watershed present even higher probabilities of 80-100%. The volumes of predicted debris flow along the main channel of McVicker Canyon range from 10K-100K cubic meters. The combined hazard presented for the main stem of McVicker Canyon is high.

Rice Canyon:

The total size of the Rice Canyon watershed in the burn area is 1,240 acres, out of which 1,235 acres burned mostly experiencing a moderate soil burn severity with some major areas of high soil burn severity at the top of the watershed. Based on a flight recon and aerial photography it is evident that in the past numerous slope failures (Photo 8) occurred on the high slopes of this watershed, while numerous debris flow events impacted the low portions of this watershed which is scattered with large amounts of debris flow deposits. At the mouth of the Rice Canyon

Photo 6 – Debris basin in McVicker Canyon.

Photo 7 – Concrete channel and box culvert under Grand Ave. for McVicker Canyon channel.

watershed right below the boundary of the burn area is located a neighborhood and an elementary school which are at high risk of being impacted by flooding and debris flows.

Rice Canyon is underlain predominantly by Cretaceous-aged, heterogeneous, massive granitic rocks. The very upper headwaters is underlain by Jurassic-aged slightly metamorphosed sediments. Several large young landslide deposits (Holocene and late Pleistocene) are mapped in the headwaters. Young axial channel deposits (Holocene and late Pleistocene) are mapped along the channel near the canyon mouth.

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows occurring along the main stem of Rise Canyon are 60-80% while some side drainages at the top of the watershed present probabilities of 80-100%. In some of the lower side drainages probabilities range from 20-40% in some cases and 40-60% in other cases. The volumes of predicted debris flow along the main channel of Rise Canyon range from 10K-100K cubic meters. Combine hazard along the main stem of Rise Canyon is presented as high.

Photo 8 – Slope failures in Rice Canyon

Bishop Canyon:

The Bishop Canyon watershed is tucked between the Rice Canyon watershed and the Horsethief Canyon watershed. The total area of Bishop Canyon is 1,440 acres out of which 1,147 acres burned, experiencing mostly moderate soil burn severity. Based on ground surveys it seems that the VAR's in and below Bishop Canyon are relatively limited and include for the most case an access road to a private property. At the crossing of this road is a 12" culvert that is likely to be plugged and over-topped by debris and flooding.

Bishop canyon is underlain by Cretaceous-aged heterogeneous, massive granitic rocks, with the exception of a small area upslope of the outflow area which is part of the Perris Block, a geologically distinct block separated from the Santa Ana Block by the Elsinore Fault Zone. The portion of the Perris Block within the burn area near Bishop Canyon is underlain by Cretaceous-aged volcanics and Triassic-aged low-to high-grade metamorphic rocks, with young axial channel and alluvial valley deposits along channel margins.

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows occurring along the main channel of Bishop Canyon are moderate, ranging from 40-60%. The volumes of predicted debris flow along the main channel of Bishop Canyon range from 1K-10K cubic meters above the confluence with Rice Canyon and 10K–100K cubic meters below the confluence. The combined hazard presented for the main stem of Bishop Canyon is moderate.

Un-named drainages between Bishop Canyon and Horsethief Canyon:

Between Bishop Canyon and Horsethief Canyon are a couple of un-named drainages which flow below a densely populated neighborhood (Photo 9). Near the mouth of these watershed, the drainages flow under Mountain Road via concrete box culverts covered by a metal grate (Photo 10). Based on the burn conditions of these drainages it is likely that these culverts will be plugged by woody debris which might lead to flooding and impacts to the neighborhood below.

These unnamed drainages are underlain by heterogeneous, Cretaceous-aged, massive granitic rocks. Old and very old alluvial fan deposits (Pleistocene) are mapped at the base of these small drainages.

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows discharging out of these un-named drainages range from 20-40% in one drainage to 40-60% in a second drainage. The volumes of predicted debris flow discharging out of these drainages range from <1K cubic

Photo 9 – Densely populated neighborhood below small, unnamed drainages east of Horsethief Canyon.

Photo 10 – Metal grate over culvert for unnamed drainage east of Horsethief.

meters in one drainage to 1K–10K cubic meters in the second drainage. The combined hazard presented for these two drainages is low for one drainage and moderate for the second drainage.

Horsethief and Cow Canyons:

The total area of the Horsethief Canyon watershed is 2,474 acres out of which 2,159 acres burned, with a majority of these acres experiencing a moderate soil burn severity and some acres at the headwaters of the watershed experiencing a high soil burn severity.

Horsethief is underlain by Cretaceous-aged, heterogeneous, massive granitic rocks. Large young landslides (Holocene and late Pleistocene) are mapped in the headwaters and a few central areas of the watershed. Old axial channel deposits (late to middle Pleistocene) are mapped extensively along the entire valley bottom, along with young wash deposits along the active channel. The mouth of the drainage has large young alluvial fan deposits (Holocene and late Pleistocene).

Cow Canyon is underlain by Cretaceous-aged, heterogeneous granitic rocks. Sparse young landslide deposits and young wash deposits have been mapped in this watershed.

Based on the flight recon, aerial photography and the geology map the flood plain of Horsethief Canyon presents a very deep channel deposit incised by a deep channel (Photo 11). In addition, the slopes of Horsethief Canyon reveal wide-spread surface erosion. Between the channel loaded with surface erosion materials and the older, deep axial channel deposits, this canyon presents a huge amount of material potentially available to be transported in events of flooding and/or debris flows. At the mouth of Horsethief Canyon are two parallel roads - an upper un-named dirt road and a lower - Bosley Lane road, which are perpendicular to the main channel and cross over it via a few 36” culverts. The upper dirt road is located right below the confluence of Horsethief Canyon and Cow Canyon. In a likely case of flooding or debris flow it is highly possible that these culverts will be plugged and over-topped which might cause damage to the roads. Based on the historical route of the lower Horsethief channel and the very flat terrain at the mouth of Horsethief Canyon (where the old orchard is located), a common storm could present a flooding event that will impact the neighborhood adjacent and east of the old orchard.

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows occurring along the main stem of Horsethief Canyon and Cow Canyon are 60-80%, while some side top tributaries to these canyons present probabilities of 80-100%. In some of the lower side drainages probabilities range from 20-40% in some cases and 40-60% in other cases. The volumes of predicted debris flow along the main channels of Horsethief Canyon and Cow Canyon range from 10K-100K cubic meters. Combine hazard along the main stems of these Canyons is presented as high.

Photo 11 – Very deep channel deposit incised by a deep channel along Horsethief Canyon.

Indian Canyon:

The total area of the Indian Canyon watershed is 2,435 acres, out of which 2,191 acres were burned. Out of the 2,191 acres that were burned in this watershed, the majority of the lower watershed experienced a moderate soil burn severity, while major areas of the upper watershed experienced high soil burn severity.

Indian Canyon is underlain by Cretaceous-aged, heterogeneous, massive granitic rock. Young landslide deposits (Holocene and late Pleistocene) are extensively mapped throughout the watershed, with large very old axial-channel deposits (middle to early Pleistocene) along the lower half of the watershed's valley floor.

Just as the Horsethief Canyon presents a very deep channel deposit incised by a deep channel, a similar situation to a lesser degree is presented at the bottom of Indian Canyon by very old channel deposits. Just as described in Horsethief Canyon, wide spread surface erosion materials in addition to the channel deposits are potentially available to be transported by flooding events which could be added to debris flows impacting Values At Risk (VAR's) in the lower watershed, in addition to VAR's located downstream from the burn area. Some of the VAR's identified in this lower watershed include private properties, roads, the Glen Eden Sun Club Resort and the bridges crossing over Indian Canyon creek at Interstate I-15. Based on the post-fire conditions in Indian

Canyon, the location and density of the homes/structures in the Glen Eden Sun Club Resort is of very high concern regarding potential flooding and debris flows impacting this community.

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it appears like the probabilities of debris flows occurring along the main stem of Indian Canyon range from 60-80% in the lower part of the watershed and 80-100% in segments of the upper watershed. The volumes of predicted debris flow along the main stem of Indian Canyon range from 10K–100K cubic meters in the lower segment of the canyon and from 1K-10K cubic meters in some of the high segments in the drainage. The combined hazard presented for the main stem of Indian Canyon is high. It is important to emphasize that even though the USGS debris flow maps do not present a value for risk of debris flow throughout the whole length of the channel (which is related to the limitations of the model) it is probable that if a debris flow occurs along Indian Canyon, it could flow all the way down past Interstate I-15. Same should be noted for all other drainages in and below the burn area.

Mayhew Canyon:

The Mayhew watershed is a large watershed encompassing a total area of 3,107 acres out of which 2,446 acres were burned. Out of those 2,446 acres that were burned the majority of the lower watershed experienced a moderate soil burn severity while large areas of the upper watershed experienced a high soil burn severity.

Mayhew Canyon watershed is underlain predominantly by Cretaceous-aged, heterogeneous, massive granitic rocks. The lowest part of the watershed is underlain by Jurassic-aged, slightly metamorphosed sediments, upon which young alluvial fan deposits (Holocene and late Pleistocene) have been mapped along the main channel. Some young landslide deposits (Holocene and late Pleistocene) are mapped on the north-facing hillslopes in the middle of the watershed.

At the mouth of the canyon is located the Mayhew quarry site. It seems that in historical times the main stem of the channel continued flowing in a north-northeast direction. Now-a-days since the quarry is located north of the mouth of the canyon, the main stem has been diverted to the north-west by an armored channel. Based on post fire conditions, the sharp curve of the channel and the low armored banks of the channel, it is highly possible that a post fire flooding or debris flow event will breach the banks of the channel causing the main stem to flow into the quarry.

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows occurring along the main stem of Mayhew Canyon range from 60-80% in the lower segment of the canyon to 80-100% in the upper segments of the canyon. The volumes of predicted debris flow along the main

channels of Mayhew Canyon range from 10K-100K cubic meters. Combine hazard along the main stems of this Canyon is presented as high.

Coldwater Canyon:

The total area of the Coldwater Canyon watershed is 2,639 acres, out of which 2,603 acres burned during the Holy Fire. Based on the air recon and the soil burn severity map it appears that this watershed experienced high soil burn severity at the higher areas of the watershed, moderate soil burn severity in the middle of the watershed and large areas of low soil burn severity or un-burned areas at the lower portion of the watershed.

Coldwater Canyon is geologically distinct on either side of the active channel – the north facing slopes are composed of Cretaceous-aged, heterogeneous, massive granitic, and the south facing slopes are composed of Jurassic-aged, slightly metamorphosed sediments. The headwaters of the canyon are underlain by Cretaceous-aged diorite.

Based on the flight recon and aerial photography it seems that in the past this watershed experienced wide-spread erosion on its slopes, especially its south facing slopes (Photo 12). In addition, based on the air recon and ground surveys the Coldwater Canyon watershed is a narrow, confined and steep canyon, which will most likely lead to increase velocity during post fire flooding and debris flow events. The mouth of the Coldwater Canyon is extremely narrow and 'spits' out directly above the Glen Ivy Hot Springs Resort and the Coldwater Canyon quarry site. Similar to the Mayhew Canyon main stem, the Coldwater Canyon main stem at its mouth takes some sharp curves and was channelized to bypass the quarry. Based on post fire conditions, the local topography, and past events, it is highly probable that flooding and debris flows will impact the Glen Ivy Hot Springs Resort and will breach into the Coldwater Canyon quarry.

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows occurring in the higher portions of the watershed range from 80-100%, and in the lower main stem of the canyon 60-80%. The volumes of predicted debris flow flowing down the main stem of the canyon range from <10K-100K cubic meters, and 1K–10K cubic meters in many of the side drainages. The combined hazard presented for the main stem of the Coldwater Canyon is high.

Photo 12 – Widespread erosion on south facing slopes of Coldwater Canyon.

Holy Jim Canyon:

Moving to the west flanks of the burn area, the Holy Jim Canyon is at the north end of the burned area. The portion of the watershed that was burned in this fire (468 acres) is relatively small in comparison to the total size of the watershed (2,038 acres). However, based on the soil burn severity, the steep slopes and widespread surface erosion at the head watershed (Photo 13), it is likely that flooding and debris flows in the higher portions of the watershed will impact VAR's (Recreation Cabins) below the fire boundary (Photo 14). The lower portion of Holy Jim trail is also likely to be impacted. Low-water crossings along the creek within the recreational resident tract may be buried or otherwise compromised.

The portion of Holy Jim Canyon in the burned area is underlain partially by heterogeneous granitic rocks and slightly metamorphosed sediments, with a few large young landslide deposits mapped in the headwaters. A small intrusion of Cretaceous-aged volcanics can be found in the very upper headwaters.

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows occurring along the main stem of this canyon range from 80-100% in the higher segments of the main stem to 60-80% in the lower segment of the main stem. The volumes of predicted debris flow flowing down the main stem of the canyon range from <1K-10K cubic meters in the higher segments of the main

Photo 13 – Severe erosion at headwaters of Holy Jim Canyon.

Photo 14 – Recreational residence tract at the base of Holy Jim canyon.

stem and 10K–100K cubic meters in the lower portion of the main stem. The combined hazard presented for the main stem of the Holy Jim Canyon is high.

Trabuco Canyon:

The Trabuco Canyon watershed is a large watershed encompassing a total area of 10,721 acres, out of which 3,989 acres were burned in the Holy Fire. Based on the soil burn severity map it seems that large areas of the north facing slopes of this watershed experienced a high soil burn severity while most of the rest experienced a moderate soil burn severity.

The Trabuco Canyon watershed is underlain predominantly by Jurassic-aged slightly metamorphosed sediments. A major headwater tributary is underlain partially by the granitics. This watershed has the highest density of mapped young landslide deposits (Holocene and late Pleistocene), covering significant areas of steep slopes in the headwaters and from mid-slopes down to the active channel. One large very old alluvial deposit (middle to early Pleistocene) is mapped emanating from the mouth of the major headwater tributary drainage. The active channel is filled with dissected and reworked very young wash deposits (late Holocene).

Based on air recon, aerial photography and ground surveys it is obvious that the Trabuco Canyon watershed is a steep, confined watershed with widespread erosion features on its slopes. The Trabuco channel is littered with alluvial deposits, debris flow deposits and large amounts of un-sorted, unconsolidated materials available to be transported in any post-fire flooding and/or debris flow event (Photos 15-16). The VAR's in this watershed include the remaining recreation cabins that did not burn in the fire, water quality being impacted by hazmat materials that are currently uncontained as a result of the burned cabins, the FS road along Trabuco Creek, West Horsethief and Trabuco Canyon trails, and a few non-fs private properties downstream along Arroyo Trabuco. The FS section of Trabuco Creek has several low water crossings and a large bridge that may be damaged or compromised by increased flows and debris.

Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows occurring along the main stem of this canyon are very high ranging from 60-80% in some segments and 80-100% in other segments. Many of the side tributes to the main stem present very high probabilities of 80-100% for the initiation of debris flows. The volumes of predicted debris flow flowing down the main stem of the canyon range from <1K-10K cubic meters in the higher segments of the main stem and 10K–100K cubic meters in the lower portion of the main stem. The combined hazard presented for the main stem of the Trabuco Canyon is high. Once again it is important to emphasize that even though the USGS debris flow maps do not present a value for risk of debris flow throughout the whole length of the channel (which is related to the limitations of the model) it is probable that if a debris flow occurs along Trabuco Canyon, it could flow all the way down and impact VAR's below the burn boundary. Same should be noted for all other drainages in and below the burn area.

Photo 15 – Debris flow deposits in Trabuco Canyon.

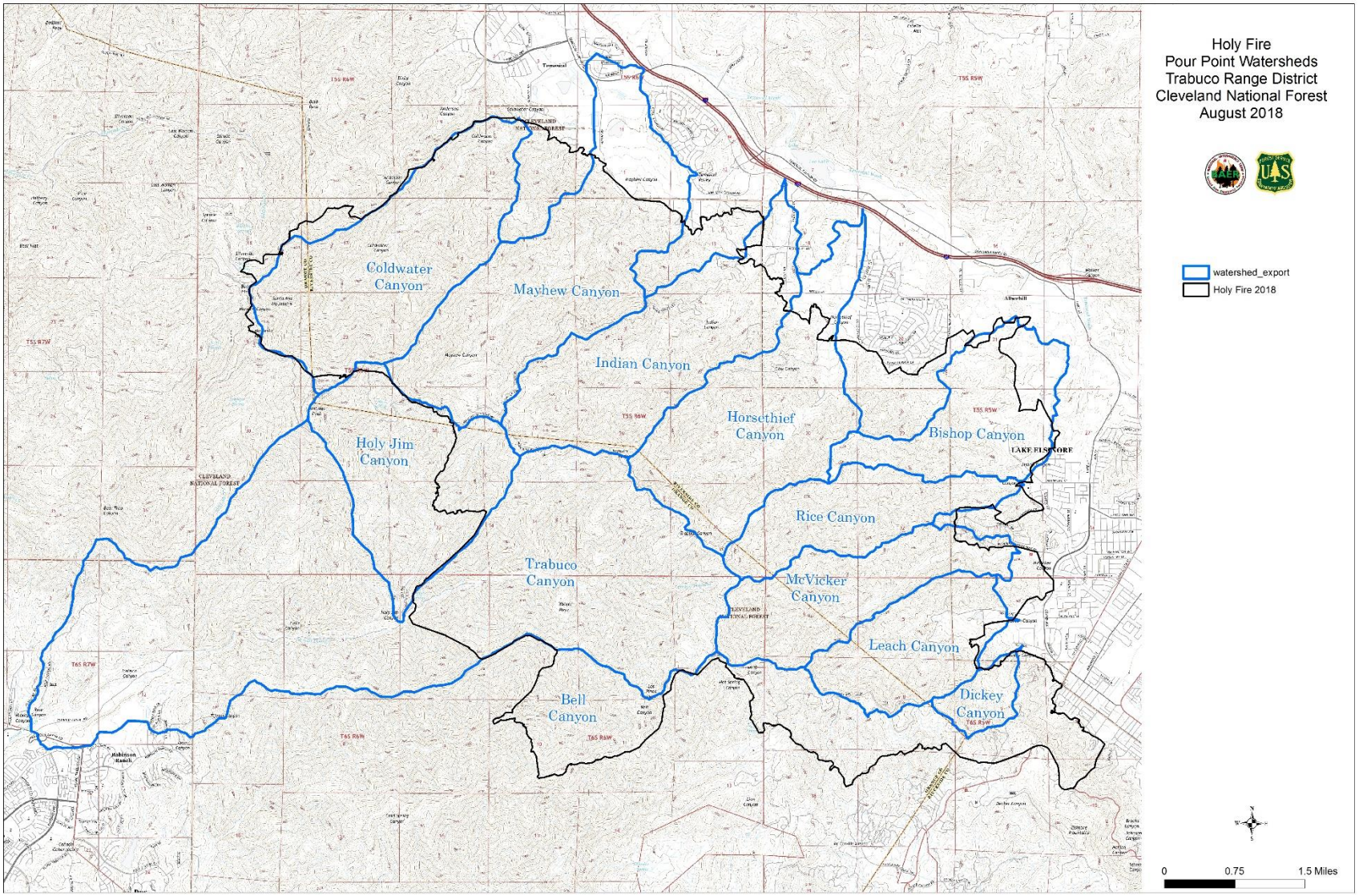
Photo 16 – Large alluvial fan deposit in Trabuco Canyon.

Bell Canyon:

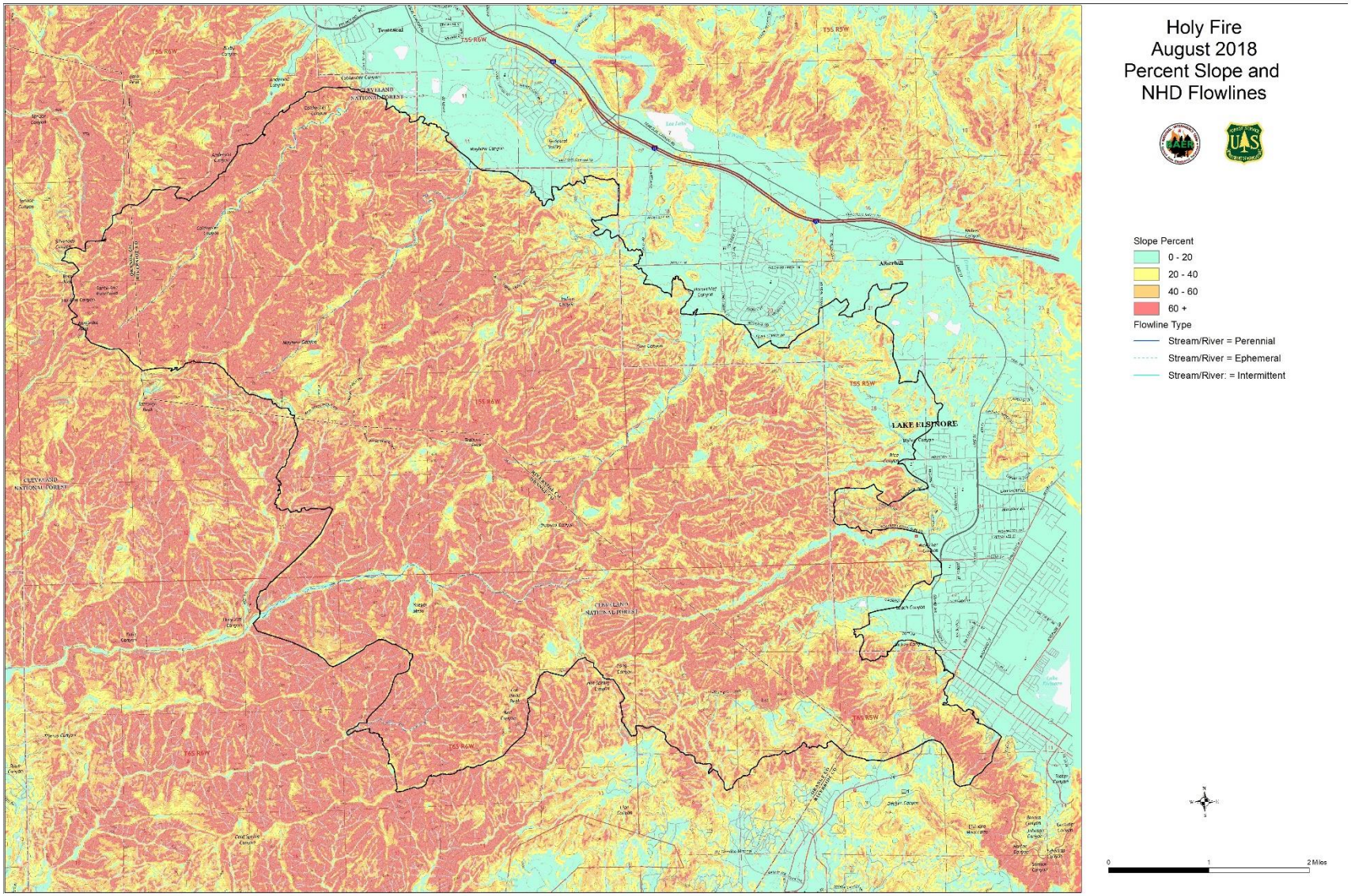
The portion of the Bell Canyon that was burned in the Holy Fire is relatively small in comparison to the total size of the watershed. Based on the soil burn severity is seems that the majority of this watershed experienced a moderate soil burn severity while other parts of the watershed experienced a high soil burn severity with some other areas which experienced a low or even very low soil burn severity. VAR's that are below the burn boundary include some neighborhoods of the Trabuco community in Orange County.

Bell Canyon watershed is underlain by Jurassic-aged slightly metamorphosed sediments. Very large young landslide deposits (Holocene and late Pleistocene have been mapped in the headwaters of the Canyon within the burn area.

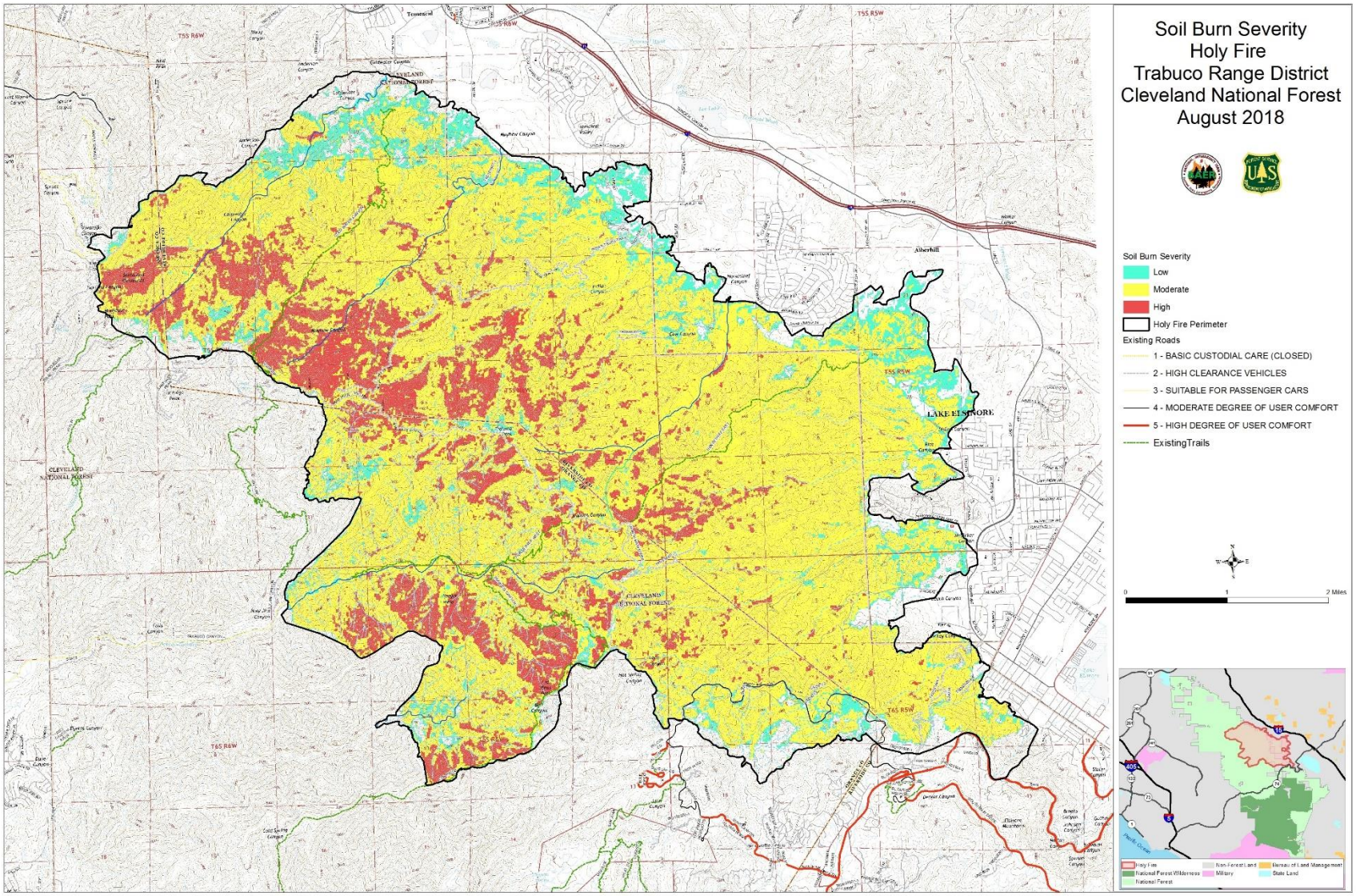
Based on USGS debris flow modeling regarding a peak 15-minute rainfall intensity of 24 millimeters (0.94 inches) per hour, it seems like the probabilities of debris flows occurring along the main stem of this canyon are very high ranging from 60-80% in some segments and 80-100% in other segments. The volumes of predicted debris flow flowing down the main stem of the canyon range from <1K-10K cubic meters in the higher segments of the main stem and 10K–100K cubic meters in the lower portion of the main stem. The combined hazard presented for the main stem of the Bell Canyon is high.



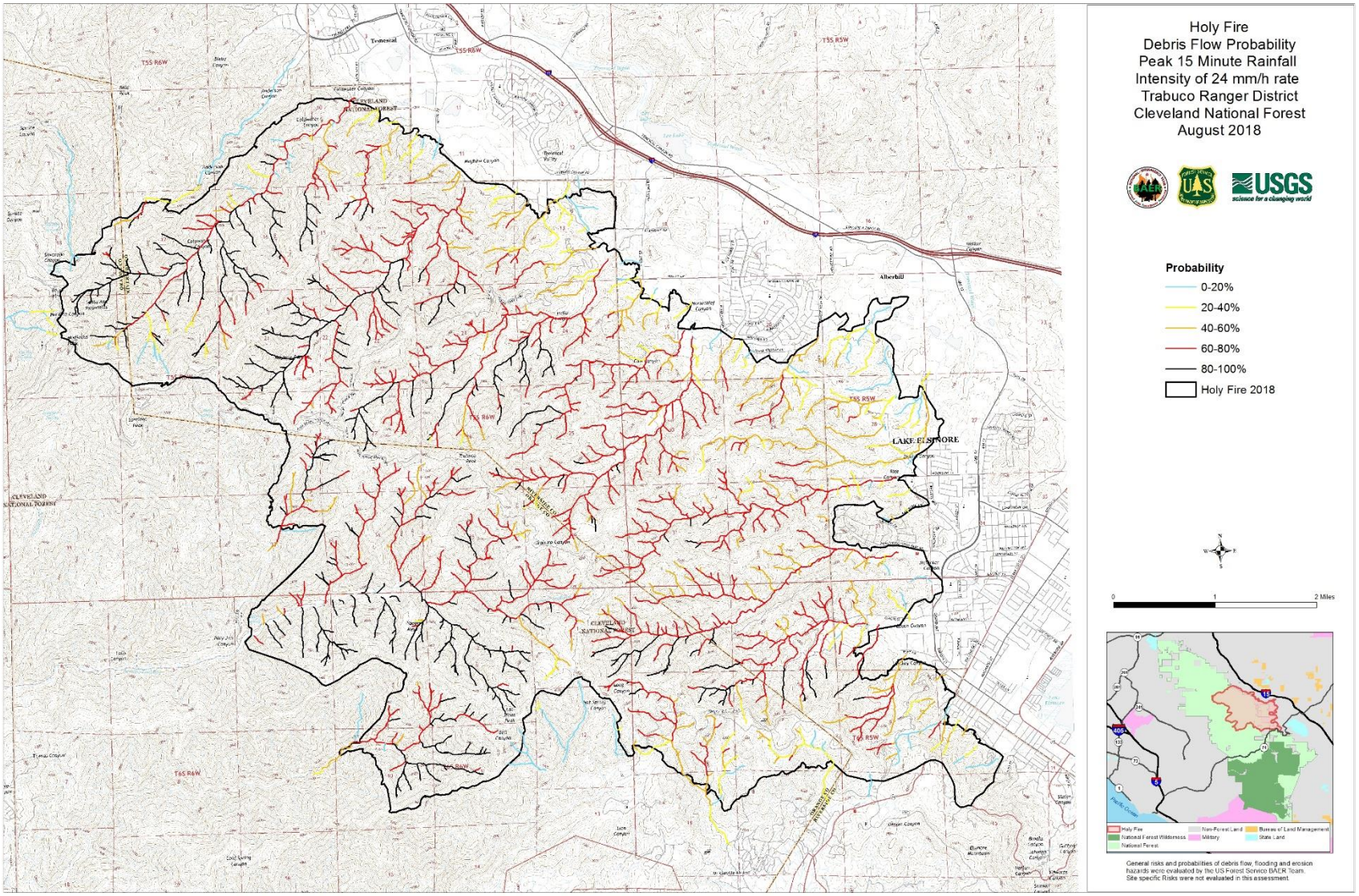
<u>Figure 4</u> – Watershed map



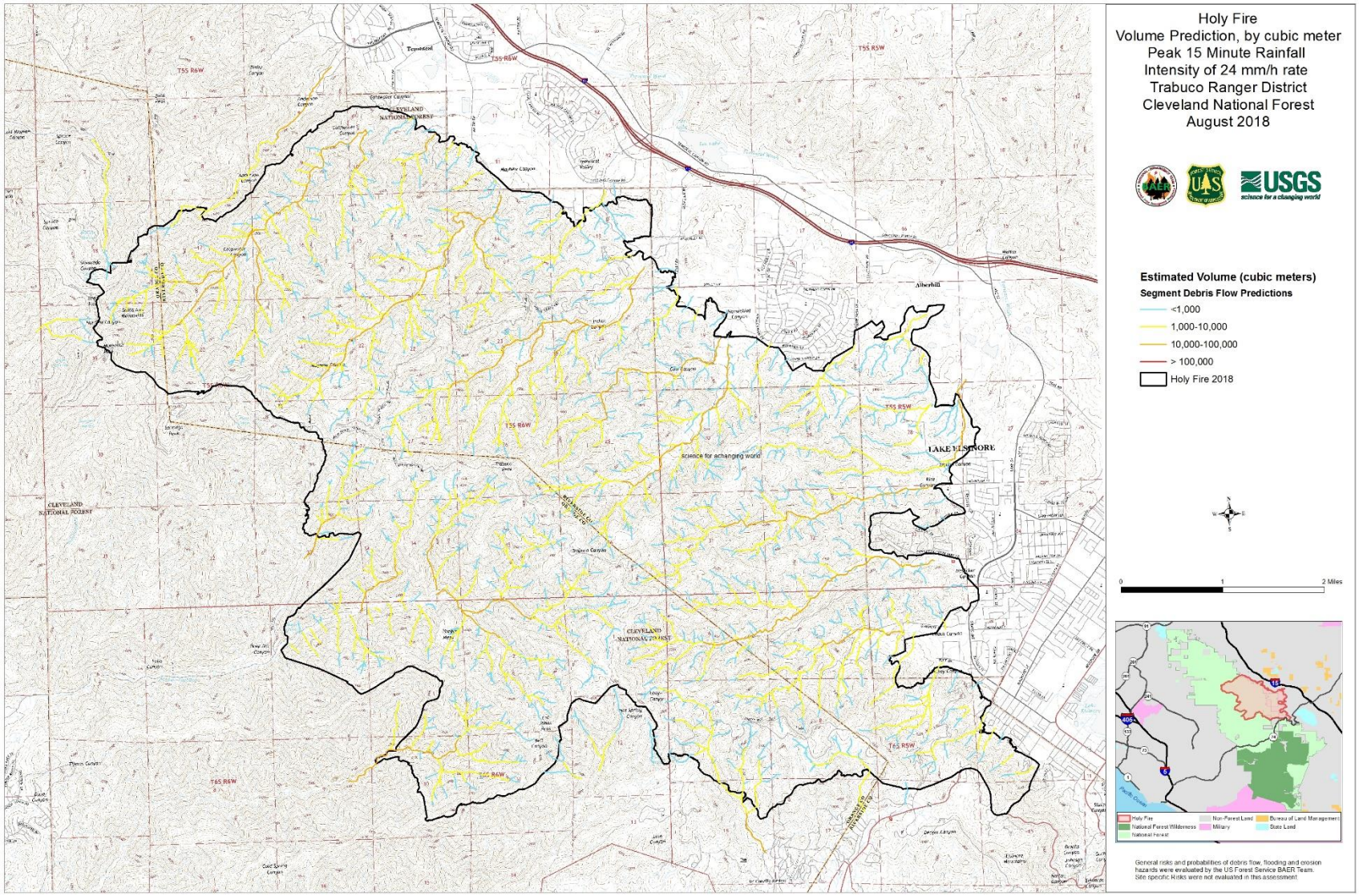
<u>Figure 5</u> – Hillslope map



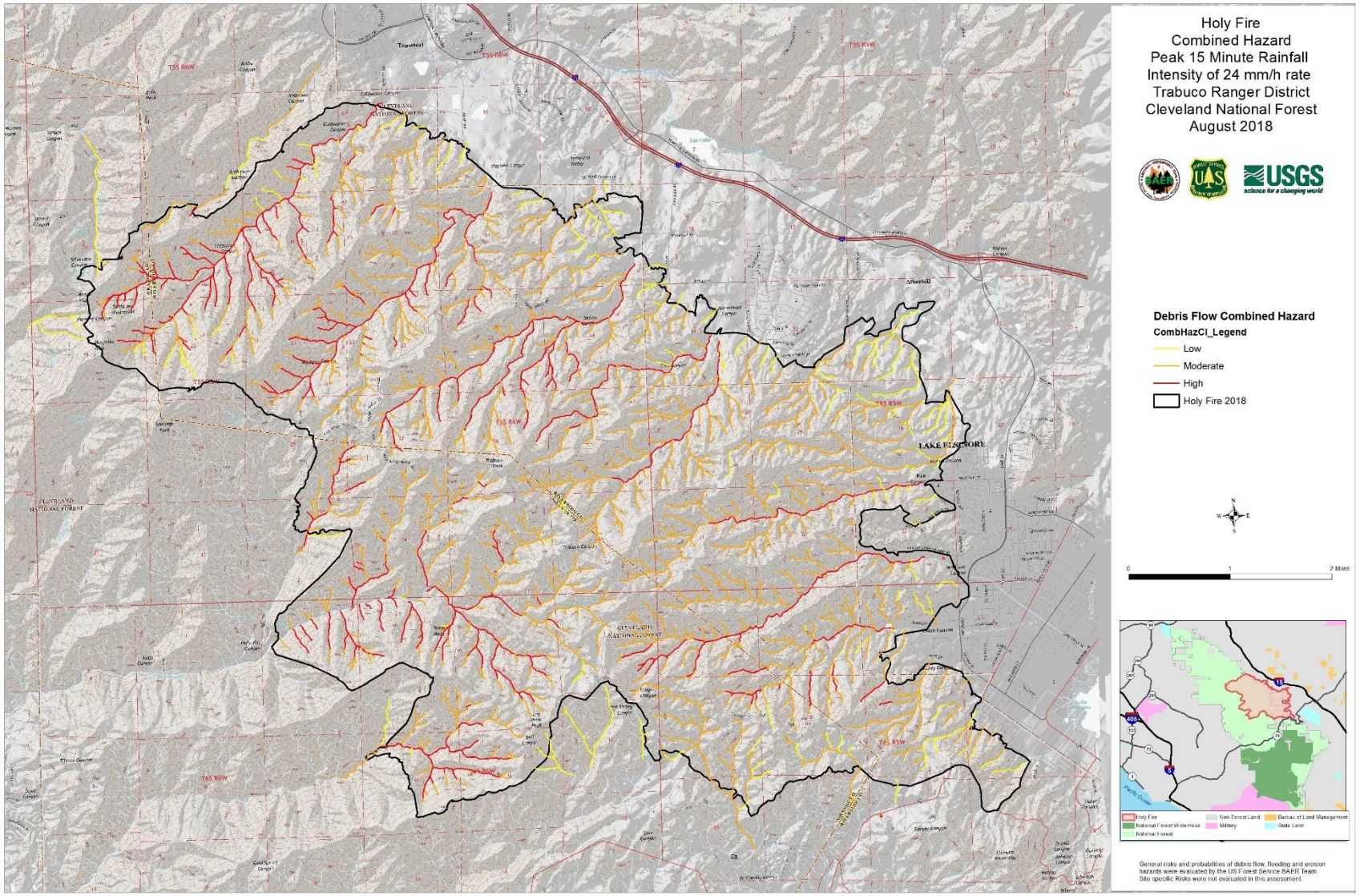
<u>Figure 6</u> – Soil burn severity



<u>Figure 7</u> – Debris Flow Probability based on a peak 15-minute rainfall intensity storm of 24 mm/h rate storm



<u>Figure 8</u> – **Debris Flow Volume based on a peak 15-minute rainfall intensity storm of 24 mm/h rate storm**



<u>Figure 9</u> – Debris Flow Combined Hazard based on a peak 15-minute rainfall intensity storm of 24 mm/h rate storm

II. Potential Values at Risk

The following "values at risk" (VARs) are threatened by debris slides and flows, rock fall, or flooding augmented by the effects of the fire on steep, erosive and unstable slopes and water channels.

Human Life and Safety:

- People living or traveling through and below burned areas or recreating in these areas – Loss of life or injury could take place as a result of debris slides, debris flows, rock-fall, or flooding.

Property:

- State, County, and Forest Service roads and bridges, private access roads and trails, and drainage systems – As a result of the fire, excessive runoff and flows, stability of slopes over roads and trails will be compromised. Debris slides, debris flows, rock-fall, and flooding could cause damage to these systems.
- Residential properties, private resorts, industrial infrastructure - As a result of the fire, excessive runoff and flows, stability of slopes over properties and infrastructure could be impacted. Debris slides, debris flows, rock-fall, and flooding could cause damage to this infrastructure.
- Water bodies such as lakes and streams - As a result of the fire, excessive runoff and flows, debris and sedimentation will adversely affect the capacity and the quality of water bodies such as lakes and streams.

Natural Resources:

- Critical habitat for Federally & State Listed Species: Sedimentation and water quality in riparian areas designated as critical habitat for Federally Listed Species – As a result of the fire, excessive sedimentation and debris will adversely affect the habitat and water quality in some of the creeks flowing through and below the burned area.

III. Emergency Determination

The emergency to VARs from geologic hazards caused by the fire includes adverse effects to the health and safety of people, property, roads, trails, Lake Elsinore and natural resources. Risk of loss of life and limb is of particular concern.

Discussion / Summary

Based on ground surveys, air recon and analyzing maps and data, rock-fall, debris slides, debris flows and dry ravel are eminent along numerus burned slopes and creeks above and around private properties, ranches, camps, industrial infrastructure and roads within watersheds burned by the Holy Fire. In addition, with the aid of USGS Debris Flow Modeling, debris flow probabilities and potential volumes have been calculated. Based on these models it appears that under conditions of a peak 15-minute rainfall intensity storm of 24 millimeters per hour (0.94 inch/hr.), the probability of debris flows occurring is high (60-80% in some channels and 80-100% in other channels) in the burn area. Under these same conditions, predicted volumes of these debris flows are expected to range from 10K-100K cubic meters in the majority of the main channels in the burned area. From the debris flow combined hazard map it appears that the majority of creeks in the burn area are predicted to produce debris flows of a high combine hazard.

The conclusion of our field observations is that whether the primary post-fire process is rock-fall, debris slides, debris flows or sediment laden flooding, the cumulative risk of various types of slope instability, sediment bulking, and channel flushing is high along many slopes and creeks in and below the burn area following the Holy Fire. Based on the above, special attention and caution is recommended in areas where people are living or traveling through, working or recreating below or in the burned areas of the Holy Fire during or after storm events. In addition, as a result of the fire, excessive sedimentation and debris could adversely affect the quality and capacity of Lake Elsinore. As a result of post-fire effects, all creeks and habitats of federally listed species flowing through and below the burned area are likely to be adversely affected by excessive sedimentation and debris flow events.

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Appendix 1: Geology Inputs to 2500-8

Part II – Burned Area Description:

Geology: The Holy Fire occurred on the Santa Ana Mountain block, bounded by the Elsinore fault zone to the east and the Christianitos fault zone to the west. The burn area is underlain predominantly by Jurassic-aged Bedford Canyon formation, a slightly metamorphosed assemblage of marine sediments, and Cretaceous-aged heterogeneous granitic formations, and overlain by Quaternary alluvial and surficial sediments to present age (Morton and Miller, 2006). Young landslide deposits, Holocene and late Pleistocene in age, are pervasive throughout the burn area due to steep topography and highly fractured rock. These deposits are composed of displaced bedrock blocks and/or poorly sorted rubble.

Geomorphology: The burned area is dominated by extremely rugged slopes, draining into Temescal Wash to the east, and flowing through Orange County to the Pacific Ocean to the west. The Santa Ana Mountains ridgeline has crest elevations of 1,200 to 1,700 m (3,940 to 5,580 ft). The east flank of the range is deeply dissected, with drainages extending four to six km (2.5 to 3.7 mi) into the mountains up to the ridgeline. Drainages on the western flank are also deeply dissected and extensively developed.

Part III – Watershed Conditions

Within the burned area of the Holy Fire, some drainages / areas show a great deal of past mass wasting as debris slide, debris flows and rock fall activity that will be increased during future storms, while other watersheds / areas have little evidence of recent past slope instability, but as conditions have changed due to the fire, erosion and new mass wasting might be initiated.

In watersheds that experienced moderate to high soil burn severity, as a result of the removal of vegetation by the fire, soils are exposed and have become weakened, and rocks on slopes have lost their supporting vegetation. Due to these post-fire new conditions, roads and trails are at risk from rolling rocks, plugged culverts, debris slides and in some cases, debris flows. Risks to human life, infrastructure, facilities, roads, trails, water bodies and natural resources is high in most areas in and downstream of the Holy Fire.

Debris Flow Potential:

The US Geological Survey (USGS) - Landslide Hazards Program, has developed empirical models for forecasting the probability and the likely volume of post-fire debris flow events. To run their models, the USGS uses geospatial data related to basin morphometry, burn severity, soil properties, and rainfall characteristics to estimate the probability and volume of debris flows that may occur in response to a design storm (Staley, 2016). Estimates of probability, volume, and combined hazard are based upon a design storm with a peak 15-minute rainfall intensity of 12 –

40 millimeters per hour (mm/h) rate. We selected a design storm of a peak 15-minute rainfall intensity of 24 millimeters per hour (mm/h) rate to evaluate debris flow potential and volumes since this magnitude of storm seems likely to occur in any given year.

Based on USGS debris flow modeling it appears that under conditions of a peak 15-minute rainfall intensity storm of 24 millimeters per hour (0.94 inch/hr.), the probability of debris flows occurring is high (60-80% in some main channels and 80 -100% in other main channels) in a majority of the main channel/creeks in the burn area. Under these same conditions, predicted volumes of these debris flows are expected to range from 10K-100K cubic meters in these same channels. From the debris flow combined hazard map it appears that the majority of creeks in the burn area are predicted to produce debris flows of a high combine hazard.