Postfire debris-flow hazard assessment

Accessing and understanding the data

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U.S. Department of the Interior
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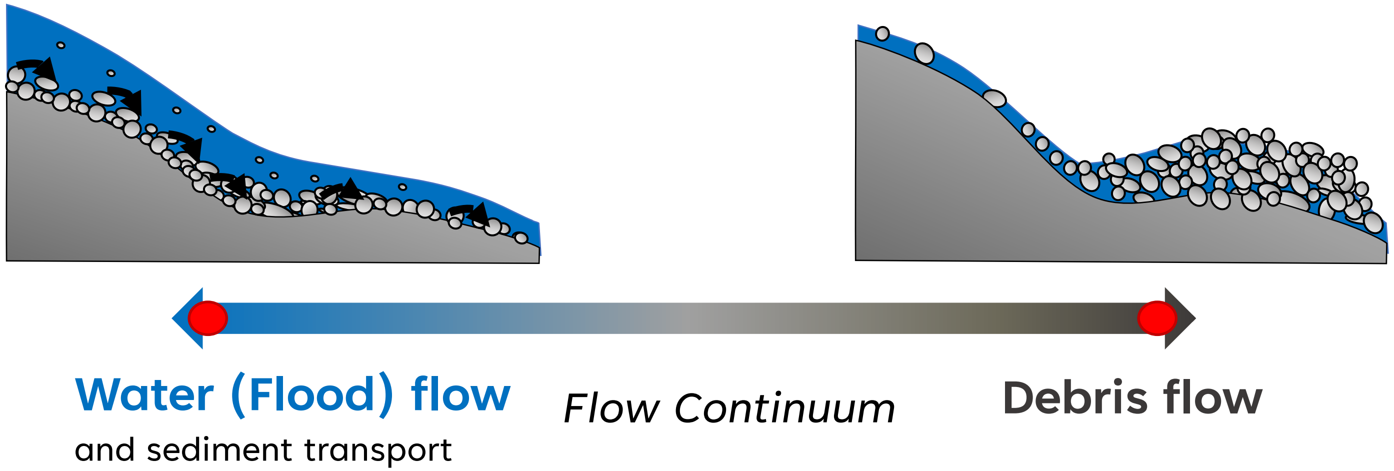
Outline

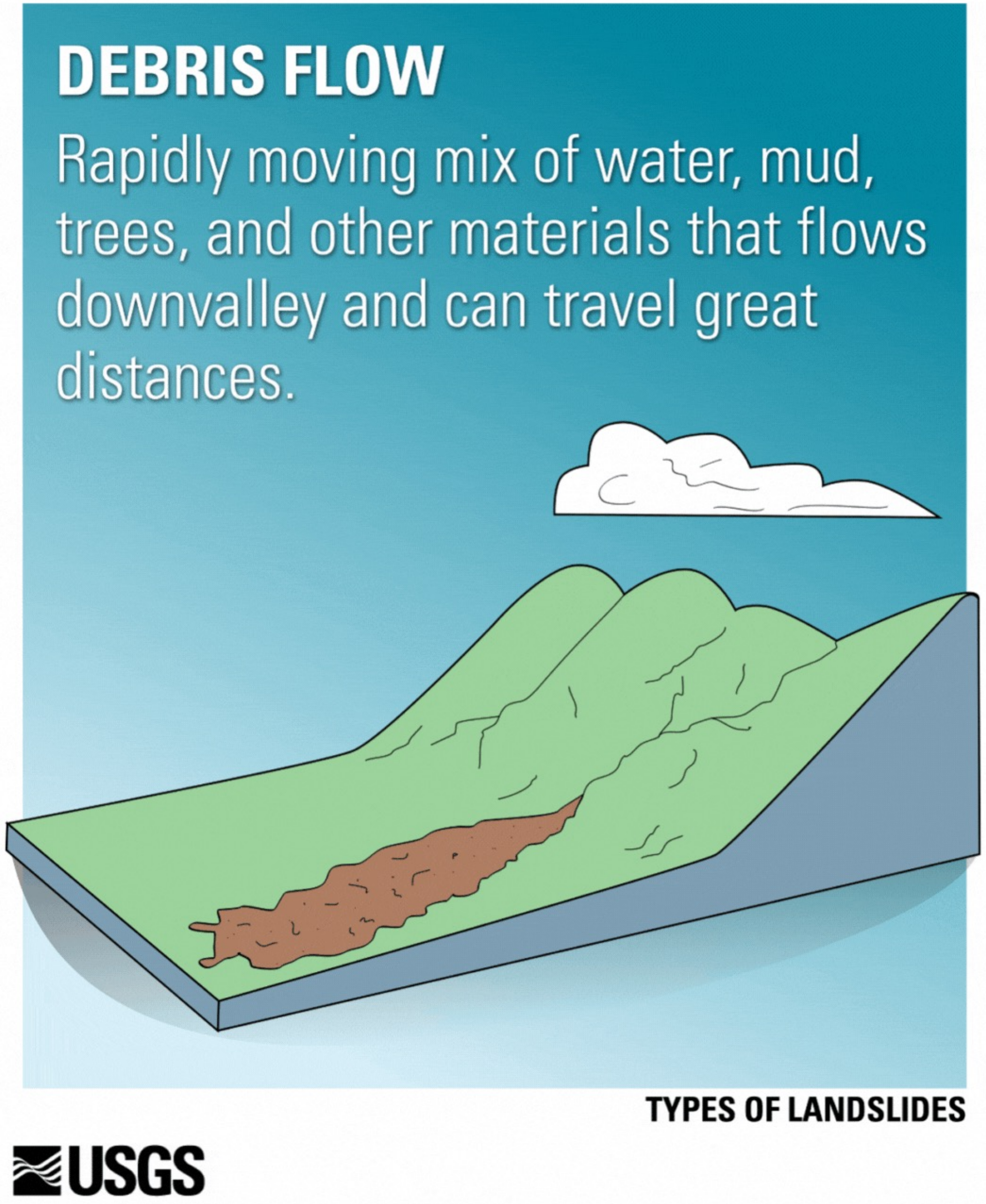
- What are postfire debris flows?
- What we do at the USGS to assess this hazard?
- Running the assessment
- Debris-flow likelihood results
- Rainfall results
- Accessing the data

What Are Post-Fire Debris-Flows?

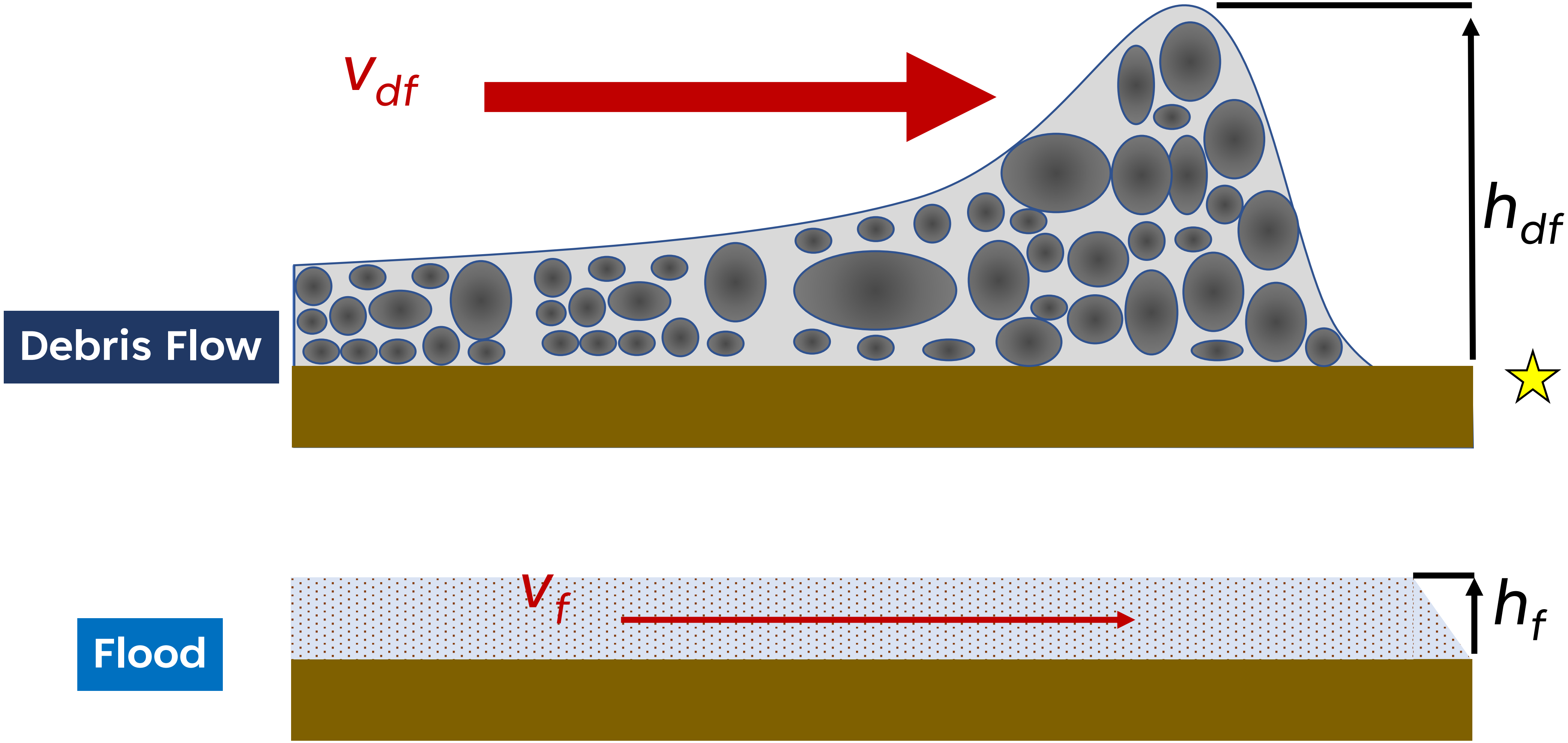
Debris flows:

- Approximately 50% sediment
- Initiate from surface runoff and erosion processes.
- Progressive entrainment of sediment.
- Often exhibit evidence of both debris-flow and flood processes.





Debris flows are worse than flash floods



☆ Flow height (h) up to 5x greater for debris flow

Flow velocity (v) can be the same or greater for debris flow

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Wildfire increases
the potential for
runoff and erosion
Wildfire
Rainfall
DEBRIS FLOW
Reduces soil
infiltration capacity
Makes soil more
easy to erode
2016 Fish Fire
Duarte, Los Angeles County, CA
USGS
science for a changing world

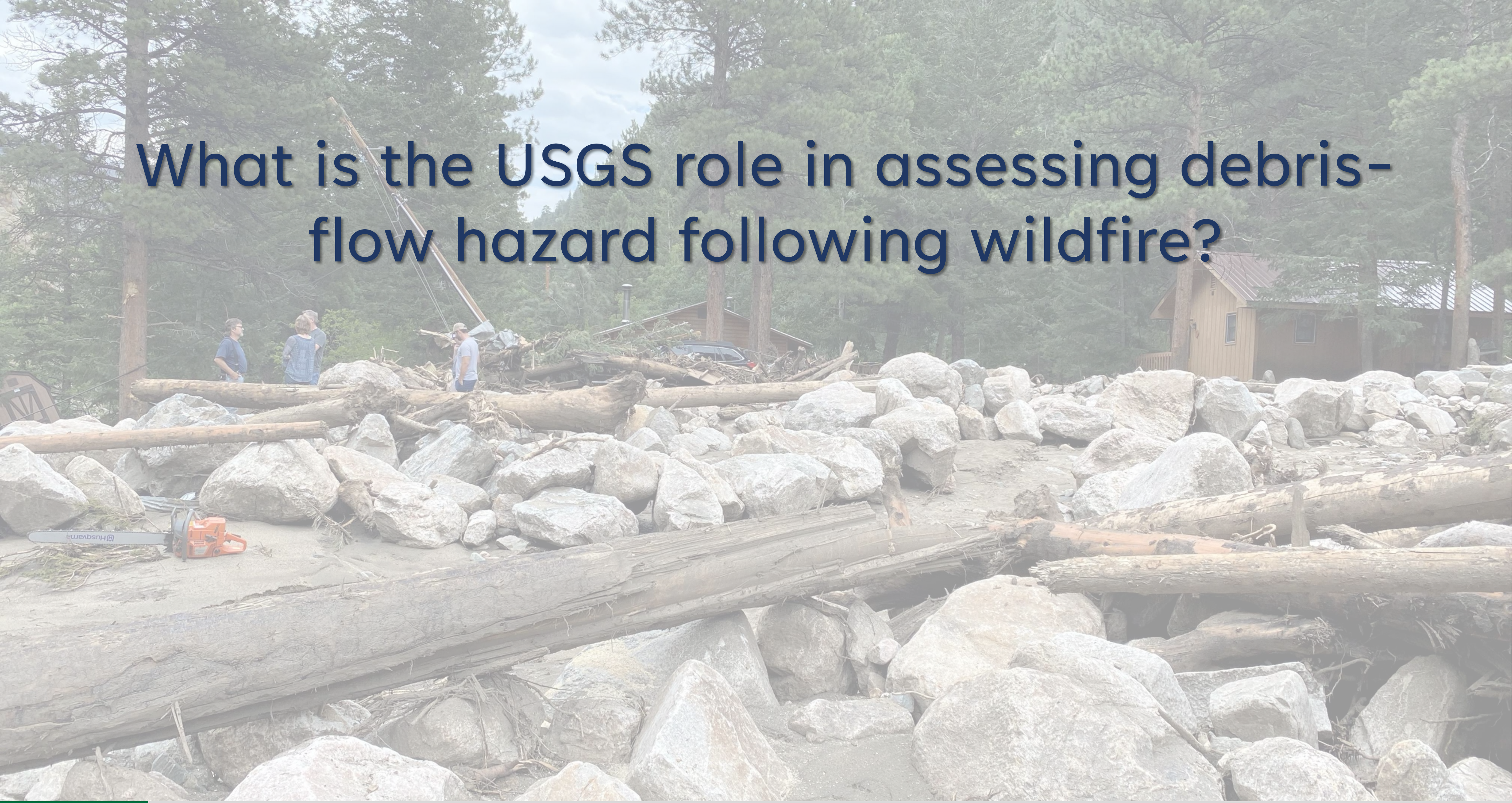
The June 2016 Fish Fire burned over 12 km^2 in Los Angeles County, California. After the fire, the USGS installed an automated rain-triggered camera to monitor post-wildfire flooding and debris flow in a small canyon above the Las Lomas debris basin in Duarte. This video shows the peak flow triggered by an intense rainstorm on January 20, 2017.

The watershed slope averages 30 degrees and is about 500 yards by 250 yards in dimension.

Las Lomas Video Timing

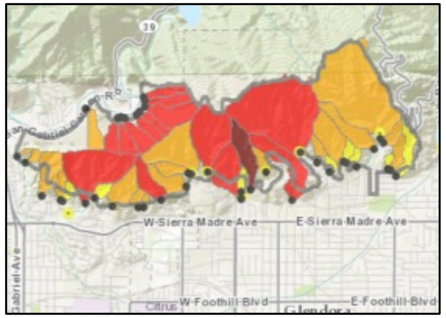
00: - 00:05: minor flooding
00:05 : sediment-laden flooding
00:20 - 00:40ish: Debris flow surge
00:40 – 00:50: More water-rich slurry, but still a debris flow
00:52 – 00:57: Big boulders!!!
00:57 – end: water-rich slurry, still df

What is the USGS role in assessing debris-flow hazard following wildfire?



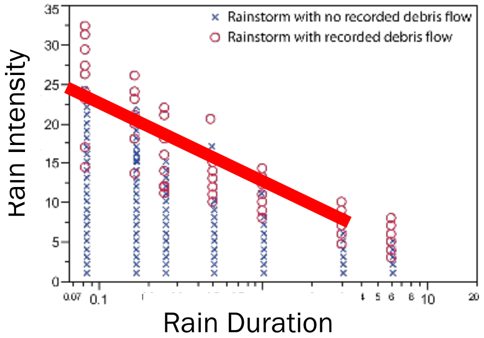
USGS Rapid assessment of debris-flow hazard

Where? *Which watersheds in the burn area are susceptible to debris flows?*



How big? *How much sediment can debris flows carry?*

When? *How hard must it rain to trigger debris flows?*



Under development

How fast/far?

Inundation model

How long?

Results are used by local, state, and federal agencies to develop post-fire emergency response plans & provide early warning.

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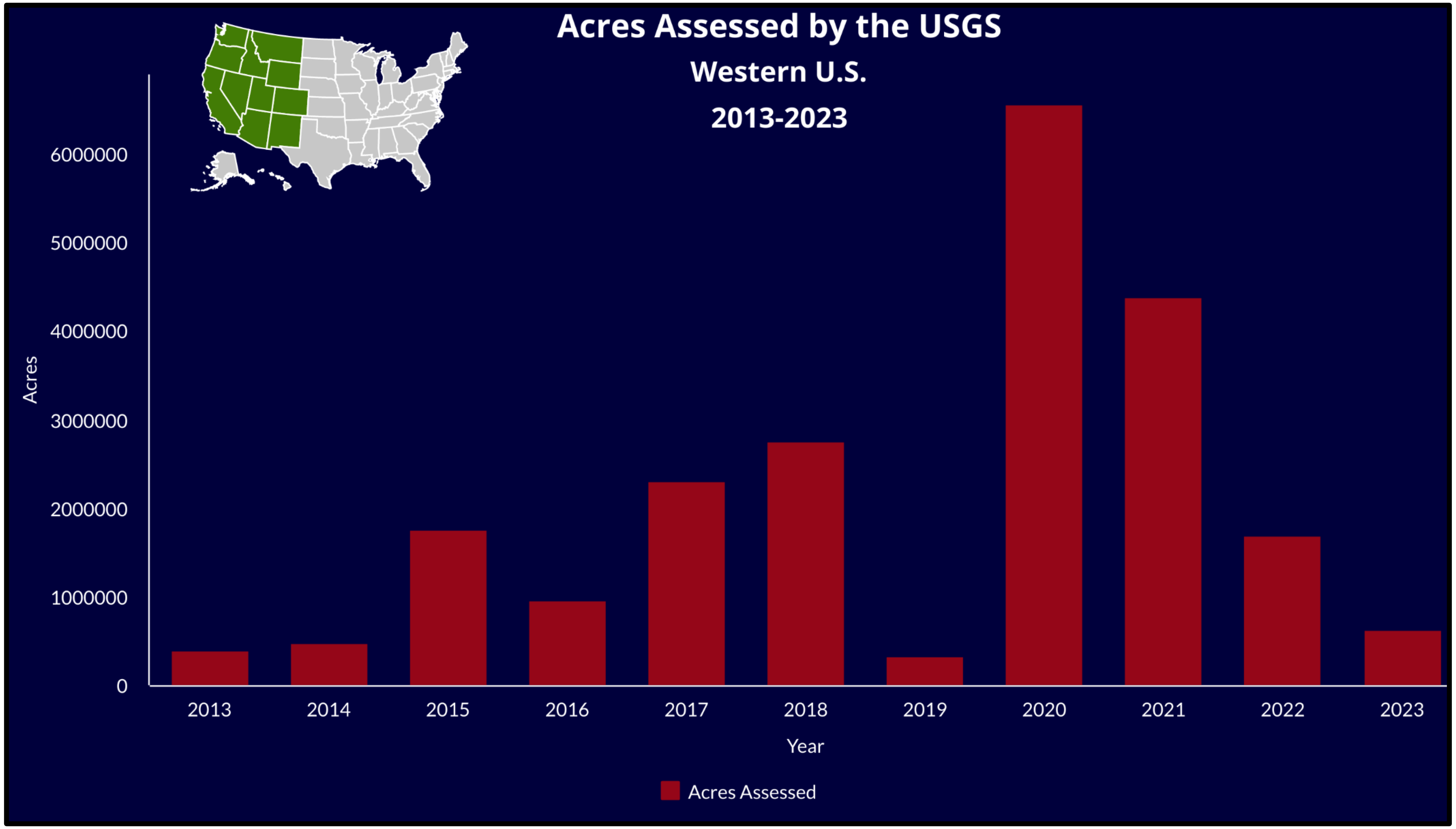
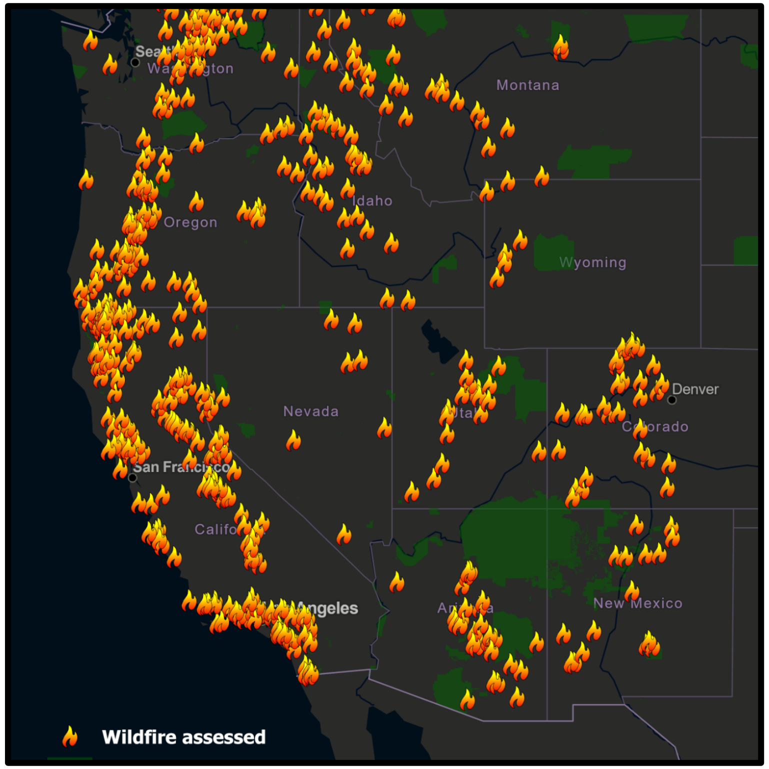
USGS Hazards Assessment 2013-2023

- 22.3 Million Acres
- 484 Wildfires
- 80 National Forest
- 11 National Parks





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USGS Hazard Assessments

2020 Cameron Peak Fire, Arapahoe & Roosevelt NF

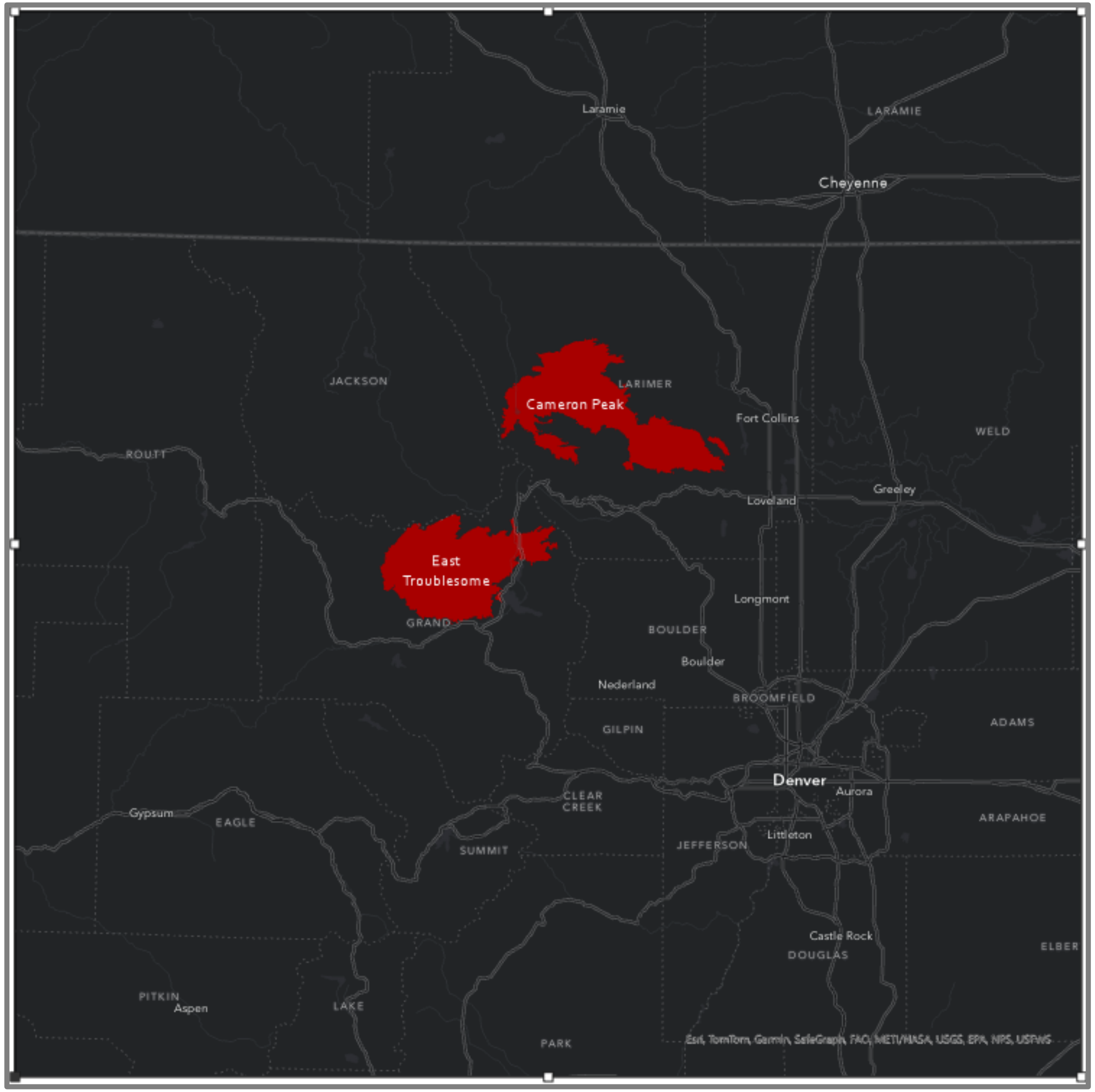
2020 East Troublesome Fire, Grand County, Colorado

Hazard maps – Where are debris flows likely?

Used by state and federal post-fire emergency response teams for evaluating values at risk.

Rainfall thresholds – How hard must it rain?

Used by NWS as guidance for issuing debris-flow watches and warnings for burn areas.



Performing an assessment

Modeling the Hazard

Post-fire hazard assessments are dependent upon readily available data

What data to do we need and where do we get it?

- Soil Data
- Terrain Data (1-meter digital elevation model)
- Land Use Data

- Fire perimeter
- Fire Severity – remote sensing products

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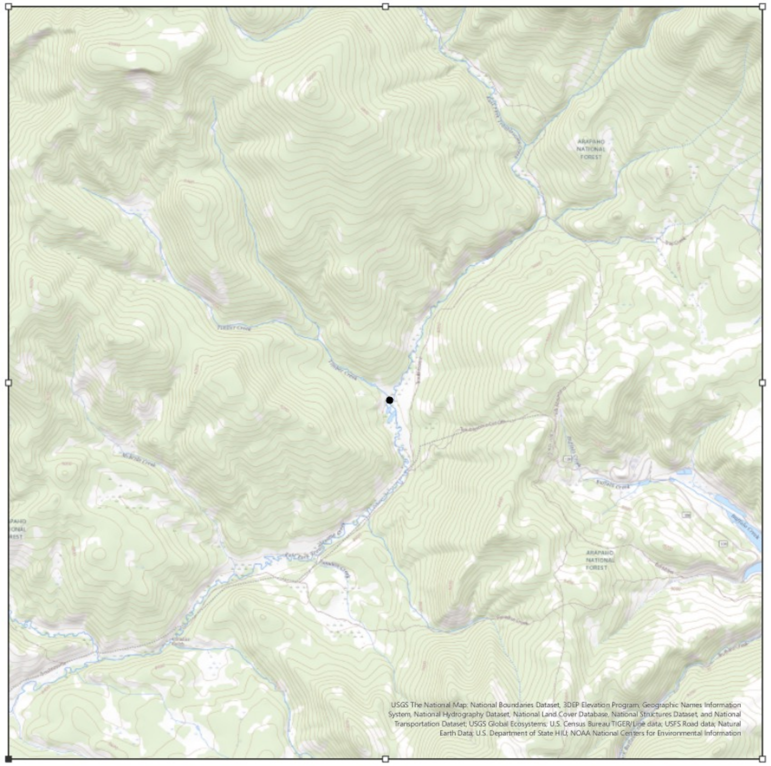
Modeling Steps

1. Delineating the watershed network
2. Model calculations and results
3. Distributing the data

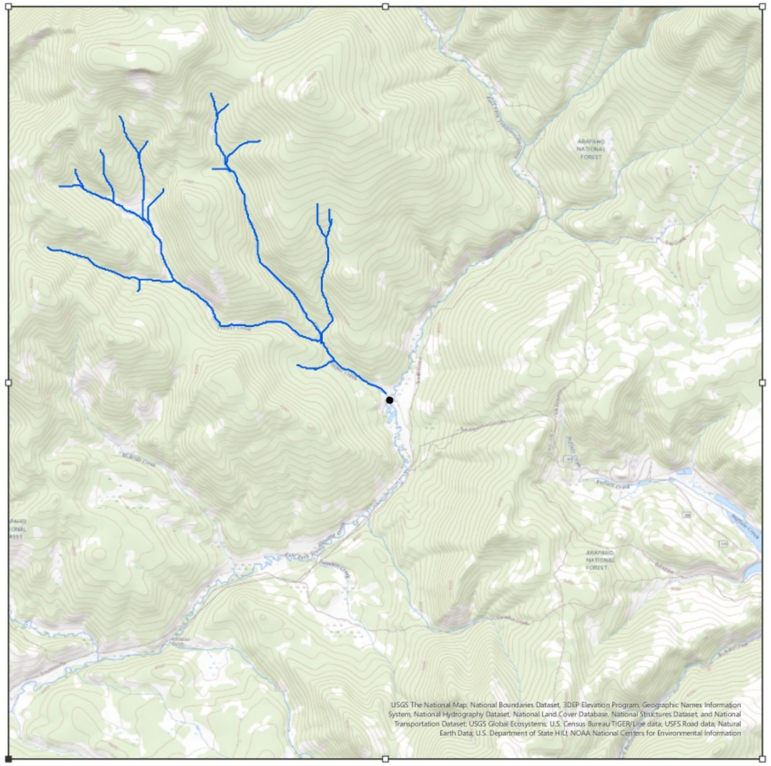
Building the watershed network

The watershed network is comprised of numerous stream segments (thousands) and small drainage basins (hundreds) in the burn area.

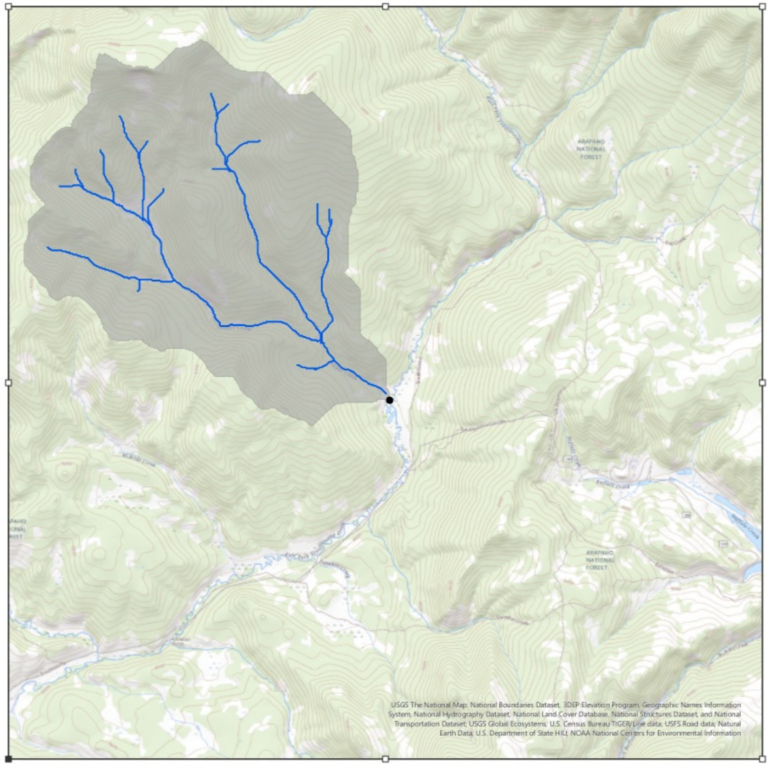
★ Criteria specific to debris flows



Basin outlet



Stream network



Drainage area

Stream reaches: 500 meters

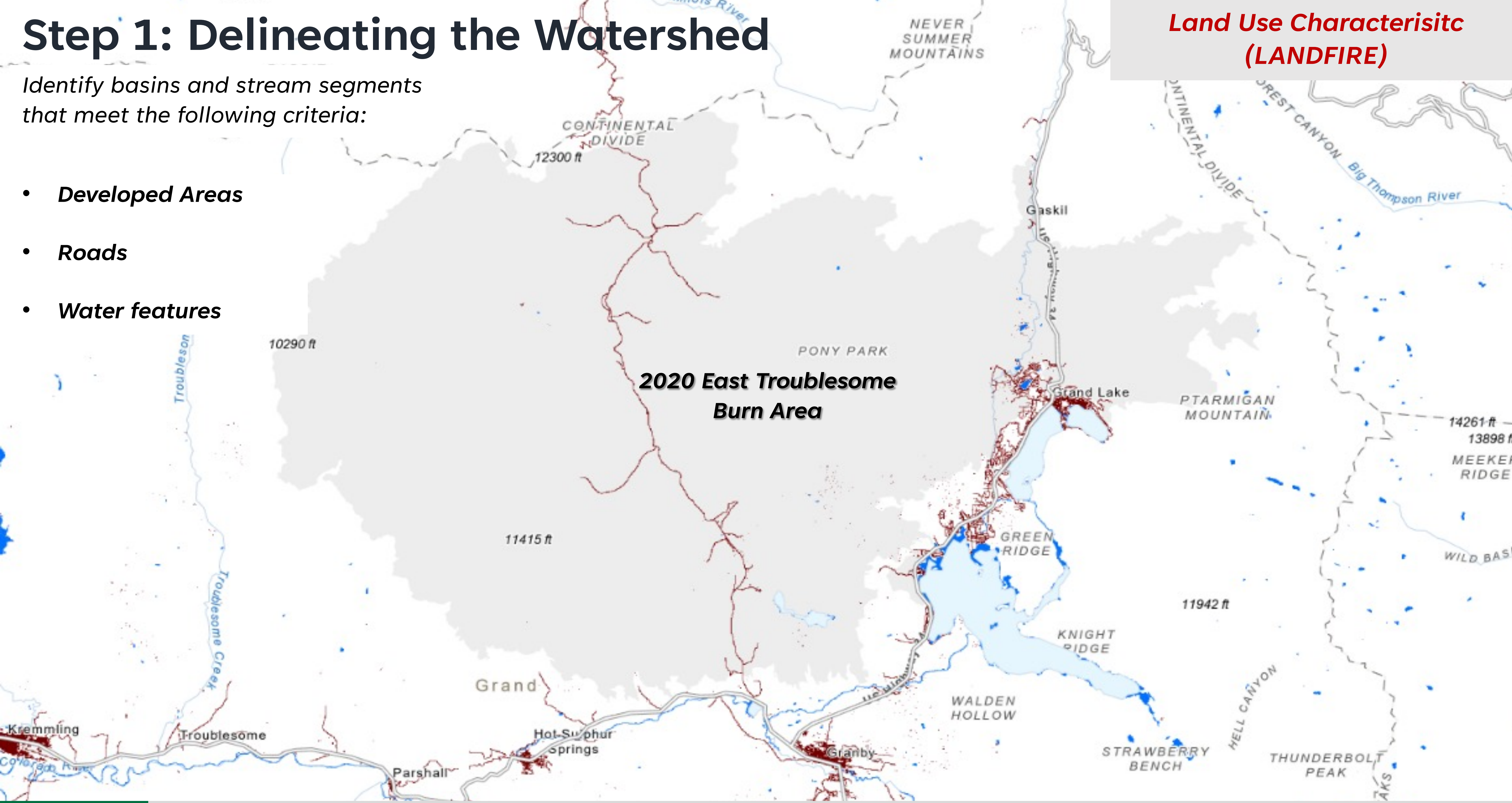
Basins: 0.25 to 8 km^2

Step 1: Delineating the Watershed

Identify basins and stream segments that meet the following criteria:

- ***Developed Areas***
- ***Roads***
- ***Water features***

Land Use Characterisitc (LANDFIRE)



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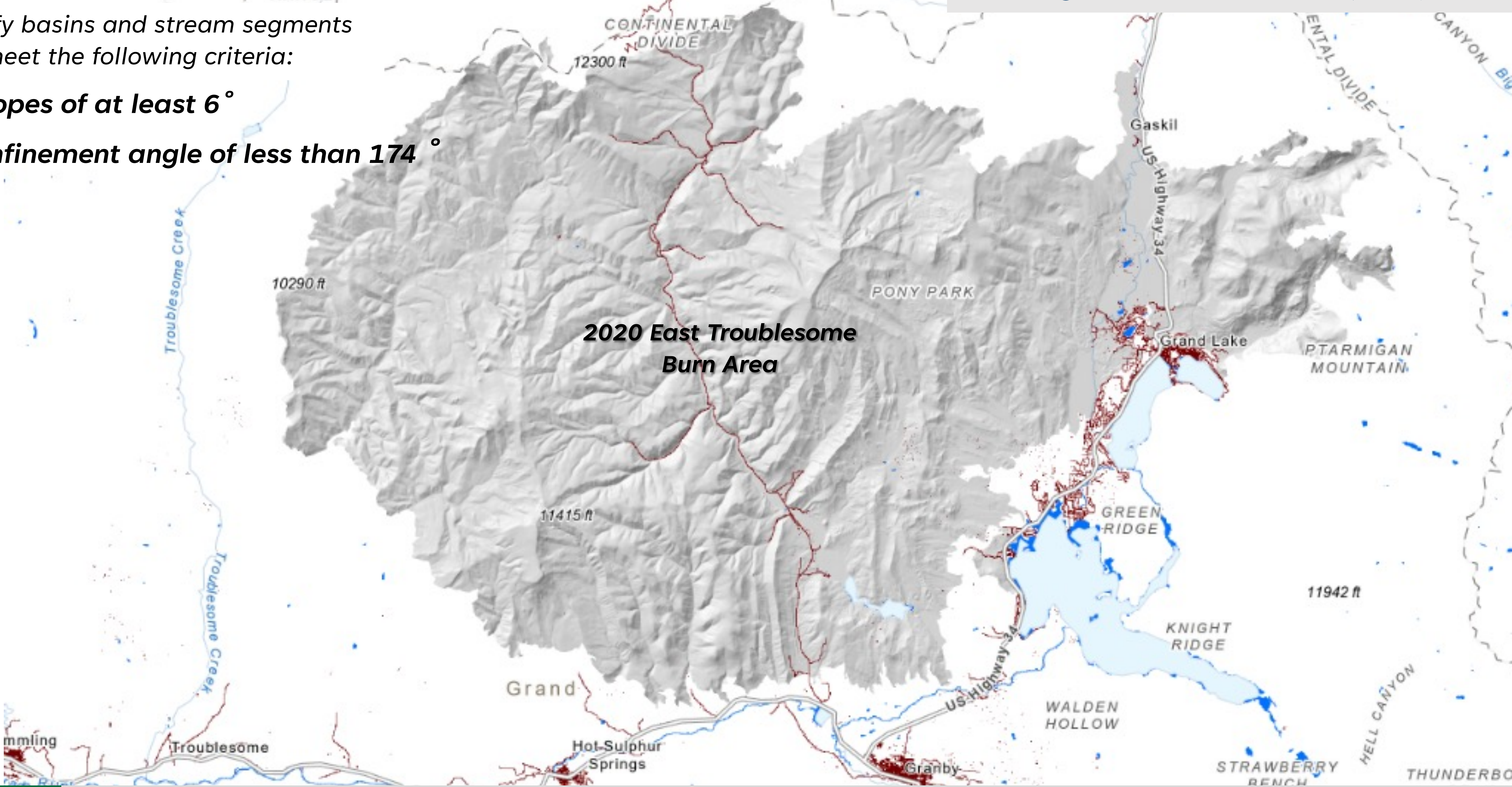
Step 1: Delineating the Watershed

Terrain Characteristics – 10-meter digital elevation model (DEM)

Identify basins and stream segments that meet the following criteria:

- ***Slopes of at least 6˚***
- ***Confinement angle of less than 174 ˚***



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Example watershed

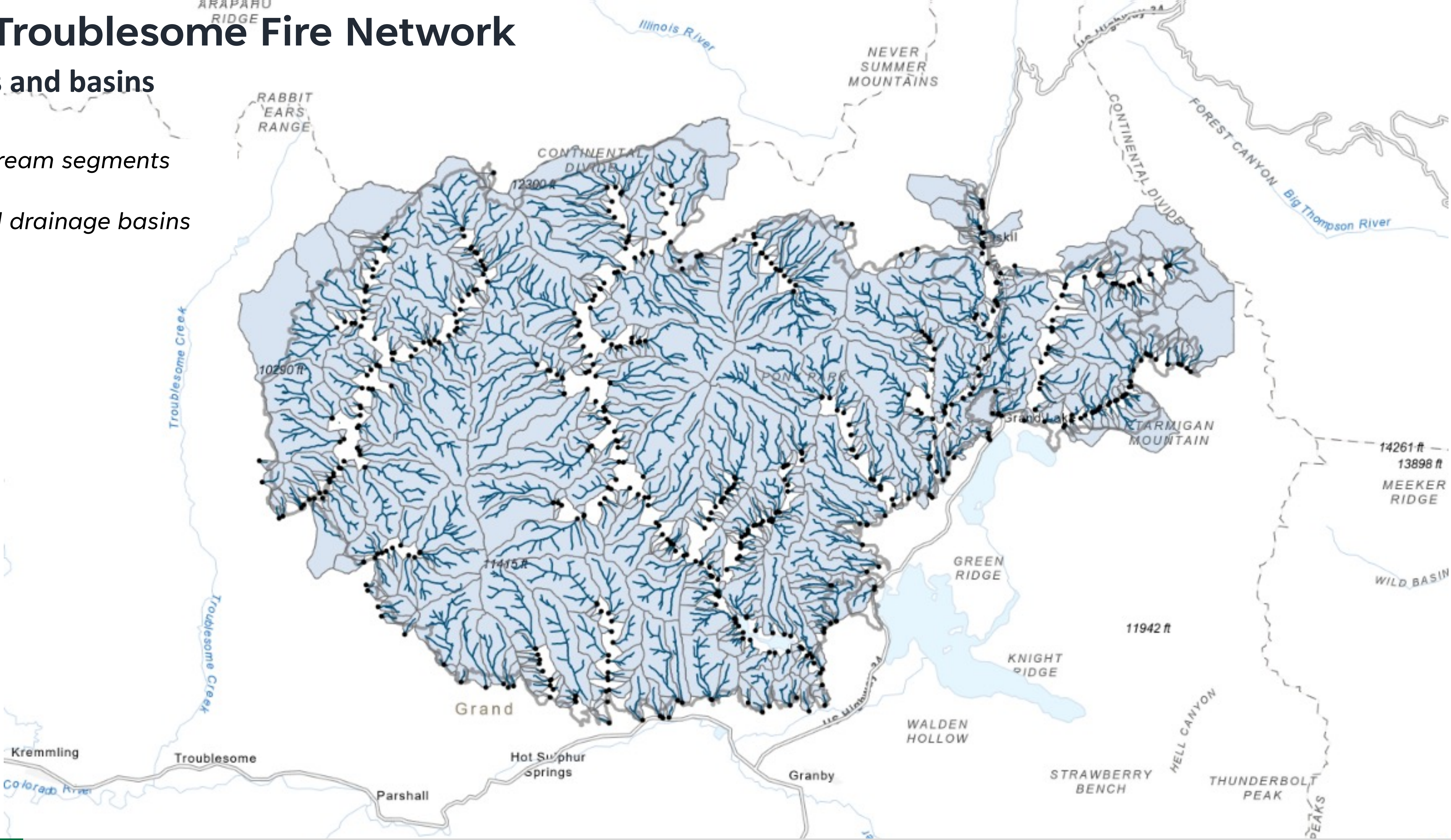
- *Avg slope of >6 degrees*
- *Confinement angle <174 degrees*

East Troublesome Fire Network

Streams and basins

10,000 Stream segments

578 Small drainage basins



Calculating the Hazard

What data to do we need and where do we get it?

- ~~Fire perimeter~~
- ~~Terrain Data (DEM)~~
- ~~Land Use Data~~

- Fire Severity – BAER TEAM
- Soils Data
- Rainfall

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Updated Logistic Regression Equations for the Calculation of Post-Fire Debris-Flow Likelihood in the Western United States

By Dennis M. Staley, Jacquelyn A. Negri, Jason W. Kean, Jayme M. Laber, Anne C. Tillery, and Ann M. Youberg

Open-File Report 2016–1106

U.S. Department of the Interior
U.S. Geological Survey

ELSEVIER

Engineering Geology
Volume 176, 24 June 2014, Pages 45-56

Empirical models for predicting volumes of sediment deposited by debris flows and sediment-laden floods in the transverse ranges of southern California

Joseph E. Gartner [a], Susan H. Cannon [a], Paul M. Santi [b]

Model Inputs

Terrain Steepness (T) + Fire Severity (F) + Rainfall (R) + Soil Properties (S) = **Likelihood**

Terrain Steepness (T) + Fire Severity (F) + Rainfall (R) = **Volume**

Calculating the Hazard

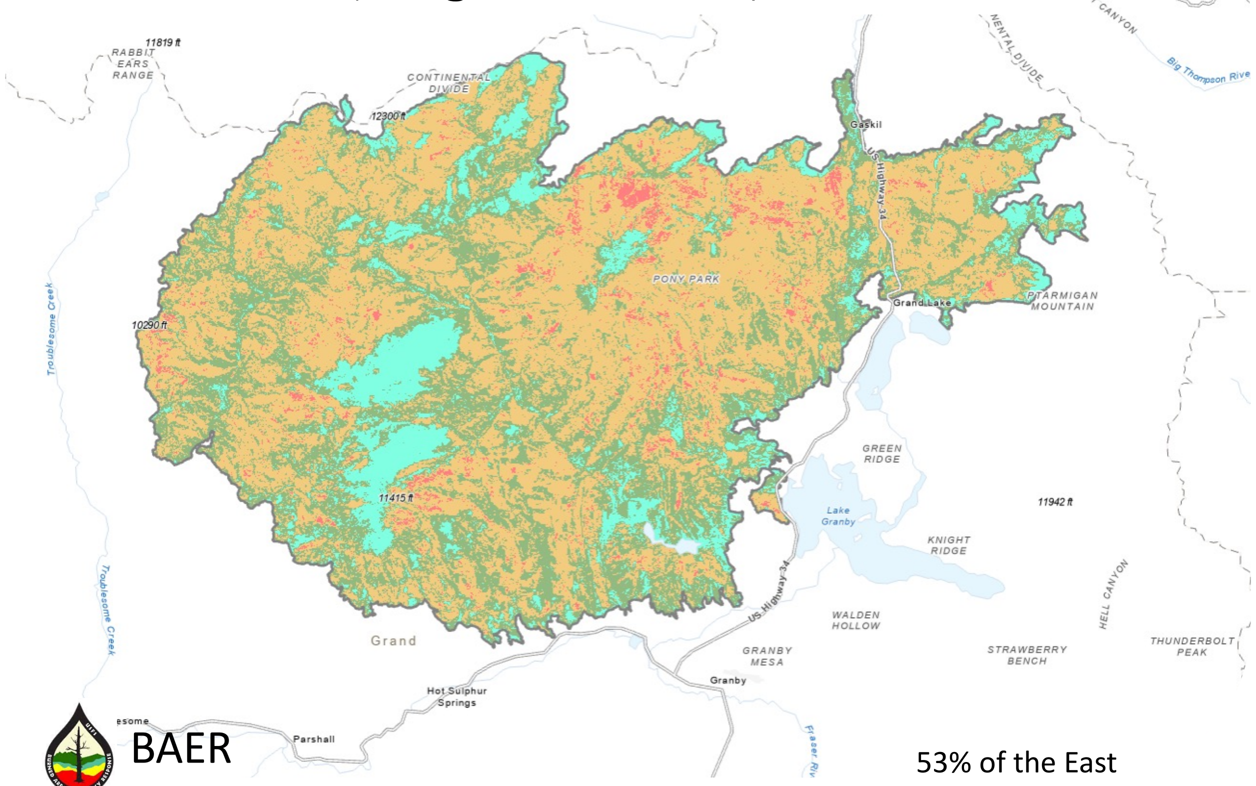
Burn Severity

dNBR

Measure of vegetation change

Soil Burn Severity

Moderate and High Severity (orange and red areas)



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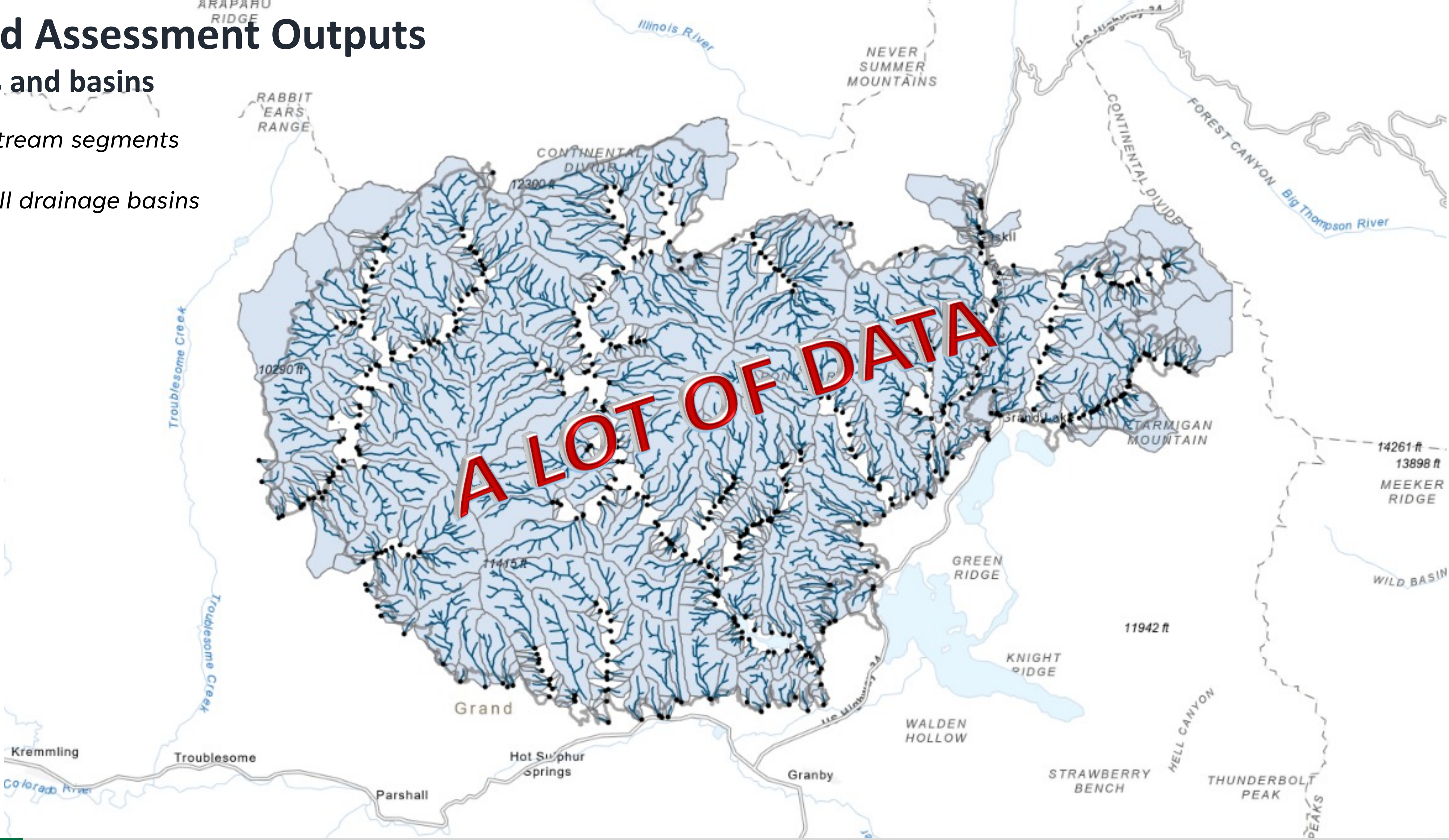
53% of the East Troublesome area is burned at high and moderate severity

Hazard Assessment Outputs

Streams and basins

10,000 Stream segments

578 Small drainage basins



Calculating the Hazard

What data to do we need and where do we get it?

- ~~Fire perimeter~~
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Calculating the Hazard

Rainfall Intensity

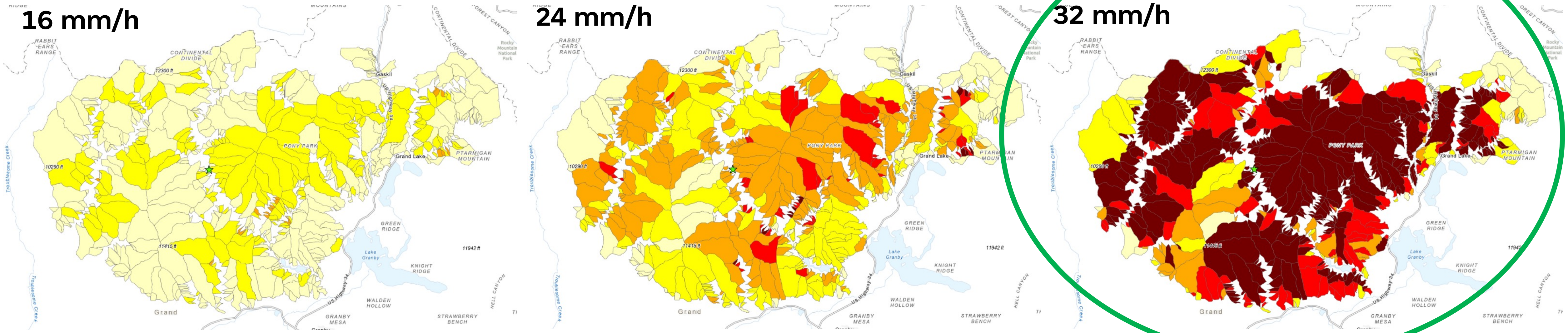
Which one of these scenarios represents a storm that can happen any given year near the East Troublesome fire?

We calculate the hazard for a variety of design storms

Design Storm: A hypothetical event with a specific rainfall depth and duration, or *intensity*

How hard is it raining?

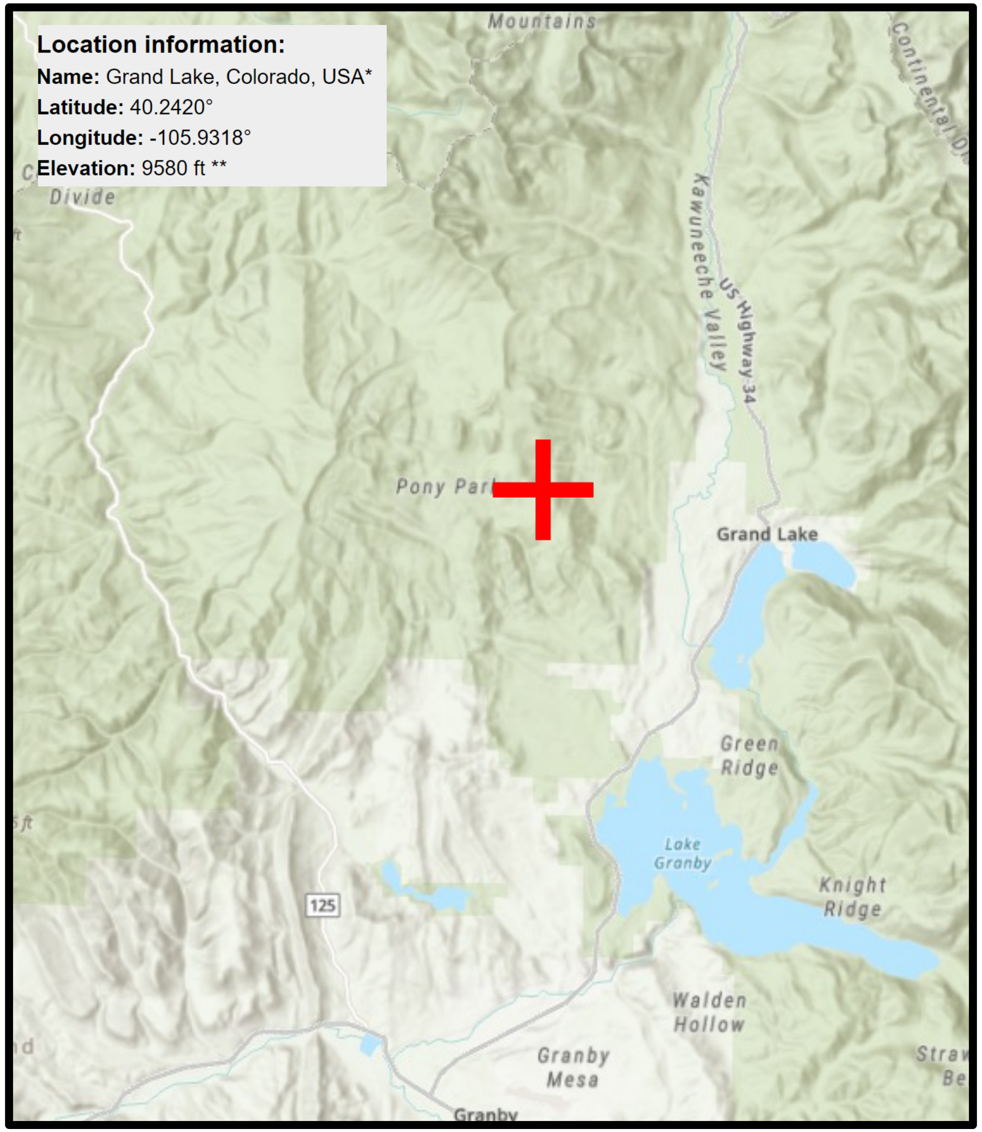
Increased rainfall intensity



Increased hazard level

Choosing the correct design storm

NOAA Atlas 14



Rainfall intensity by recurrence interval

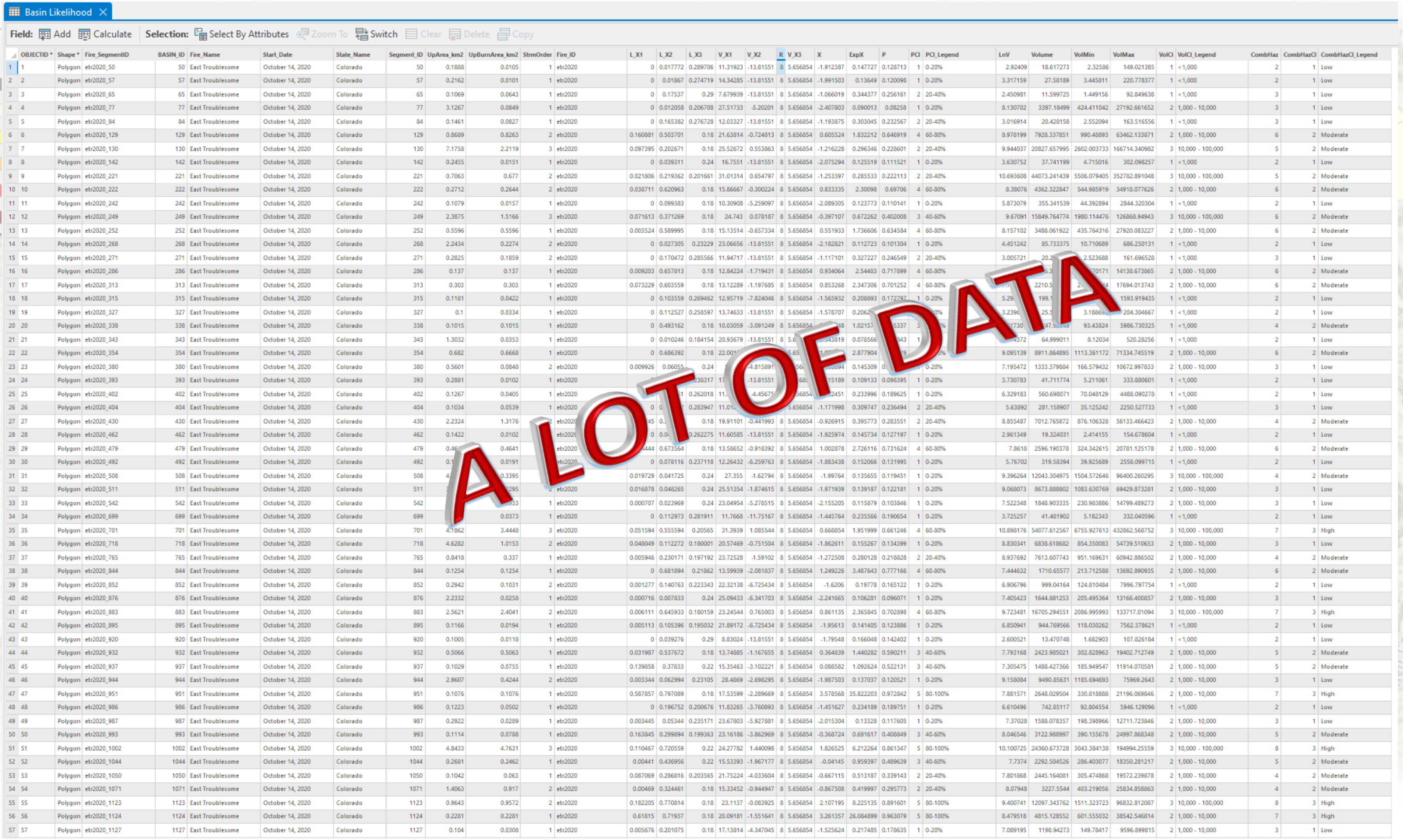
PDS-based precipitation frequency estimates with 90% confidence intervals (in millimeters/hour)[1]									
Duration	Average recurrence interval (years)								
	1	2	5	10	25	50	100	200	500
5-min	**53** (43-67)	**62** (50-79)	**80** (65-103)	**99** (79-127)	**129** (101-179)	**155** (118-218)	**186** (135-268)	**219** (151-327)	**269** (177-415)
10-min	**39** [illegible]	**45** (37-58)	**59** (47-75)	**72** (58-93)	**94** (74-131)	**114** (86-160)	**136** (99-196)	**160** (111-240)	**197** (130-304)
15-min	**31** (26-40)	**37** (30-47)	**48** (39-61)	**59** (47-75)	**77** (60-106)	**93** (70-130)	**110** (80-160)	**131** (90-195)	**160** (105-247)

Hazard Assessment Results

USGS Hazard Assessments Results

Hazard Maps

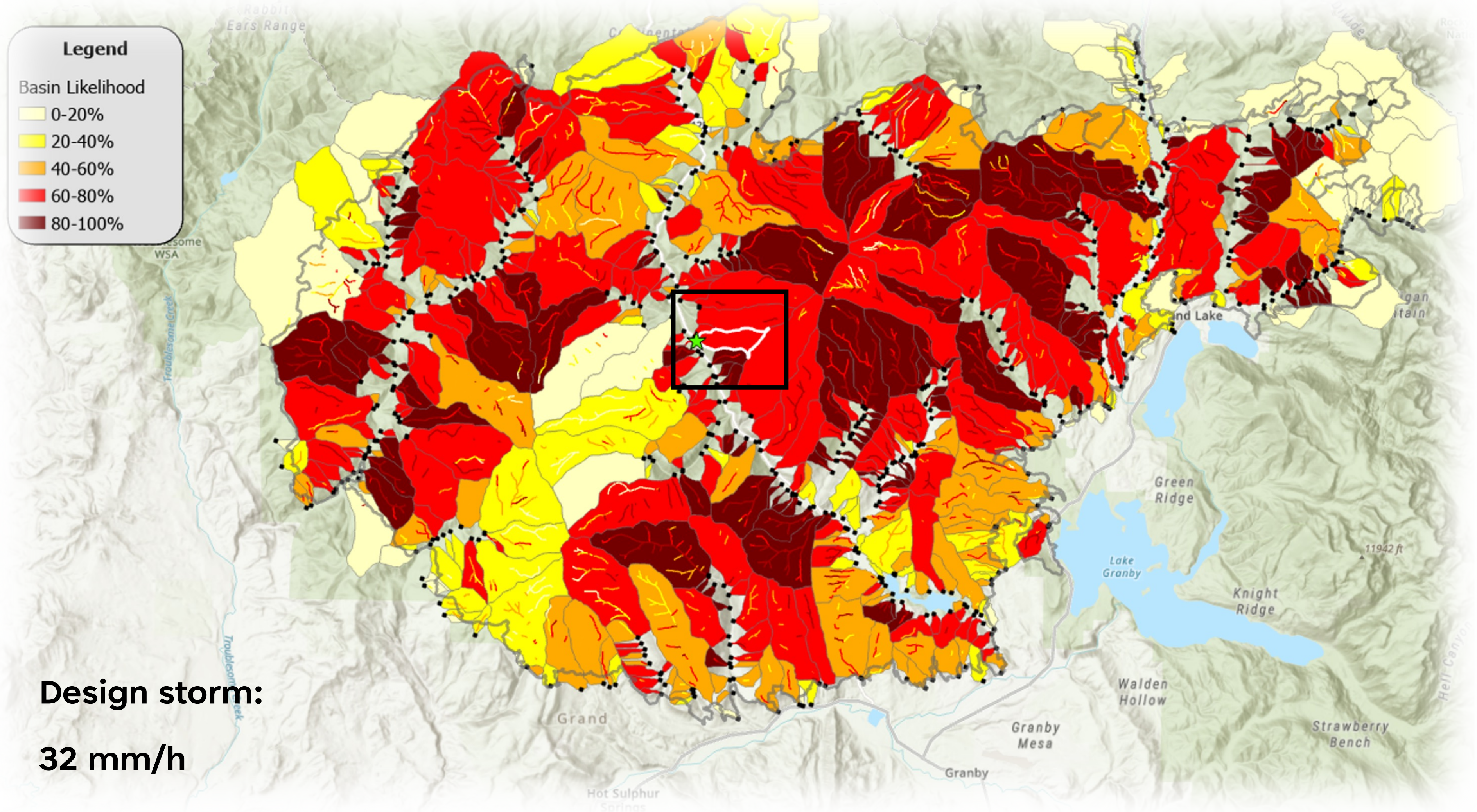
1. Likelihood
2. Volume
3. Combined Hazard



USGS Hazard Assessments Results

Hazard Maps

1. **Likelihood**
2. **Volume**
3. **Combined Hazard**

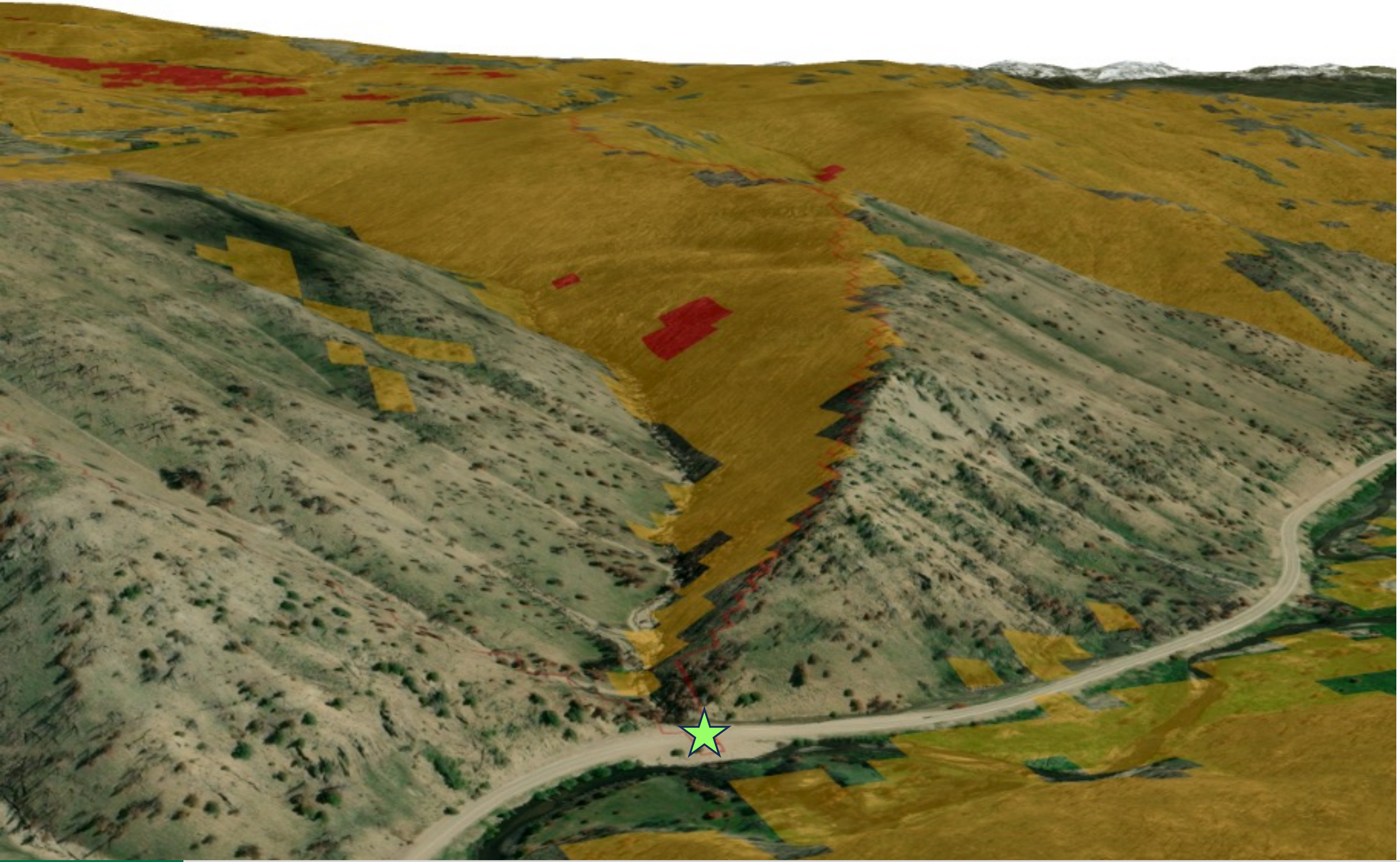


Design storm:

32 mm/h

USGS Hazard Assessments Results

Terrain Characteristic and Model Variables



Terrain Characteristics

Fire Name	East Troublesome
Start Date	14-Oct-20
State	Colorado
Area_km2	1.7363
UpBurnArea_km2	1.7343
Slope	0.16
Relief (m)	438
Confinement	170

Model Variables

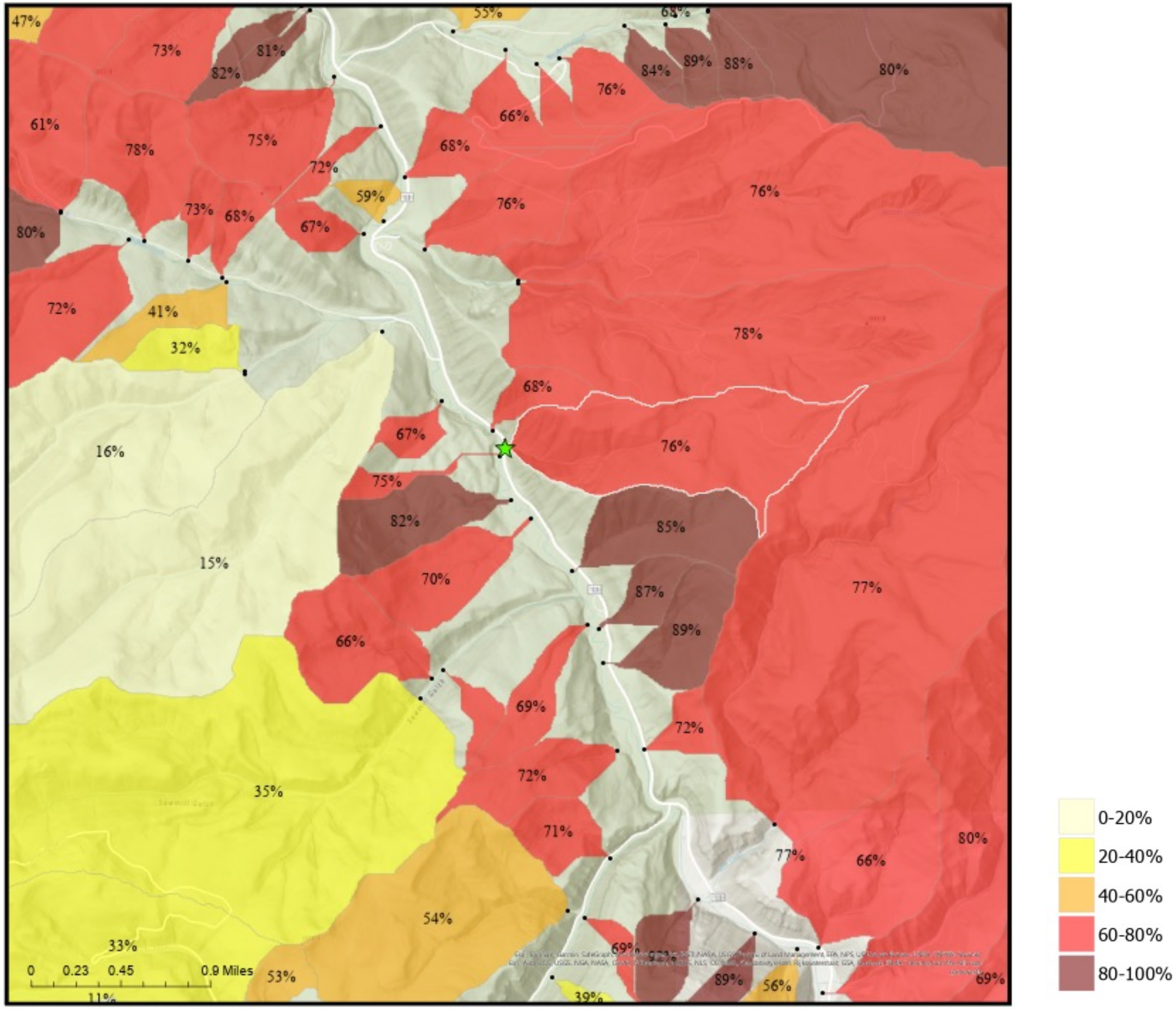
T	0.11
F	0.59
S	0.22

T = Slopes >23° burned at moderate/high severity

F = dNBR value/1000

S = Soil erodibility

USGS Hazard Assessments Results



Likelihood

Basin-scale

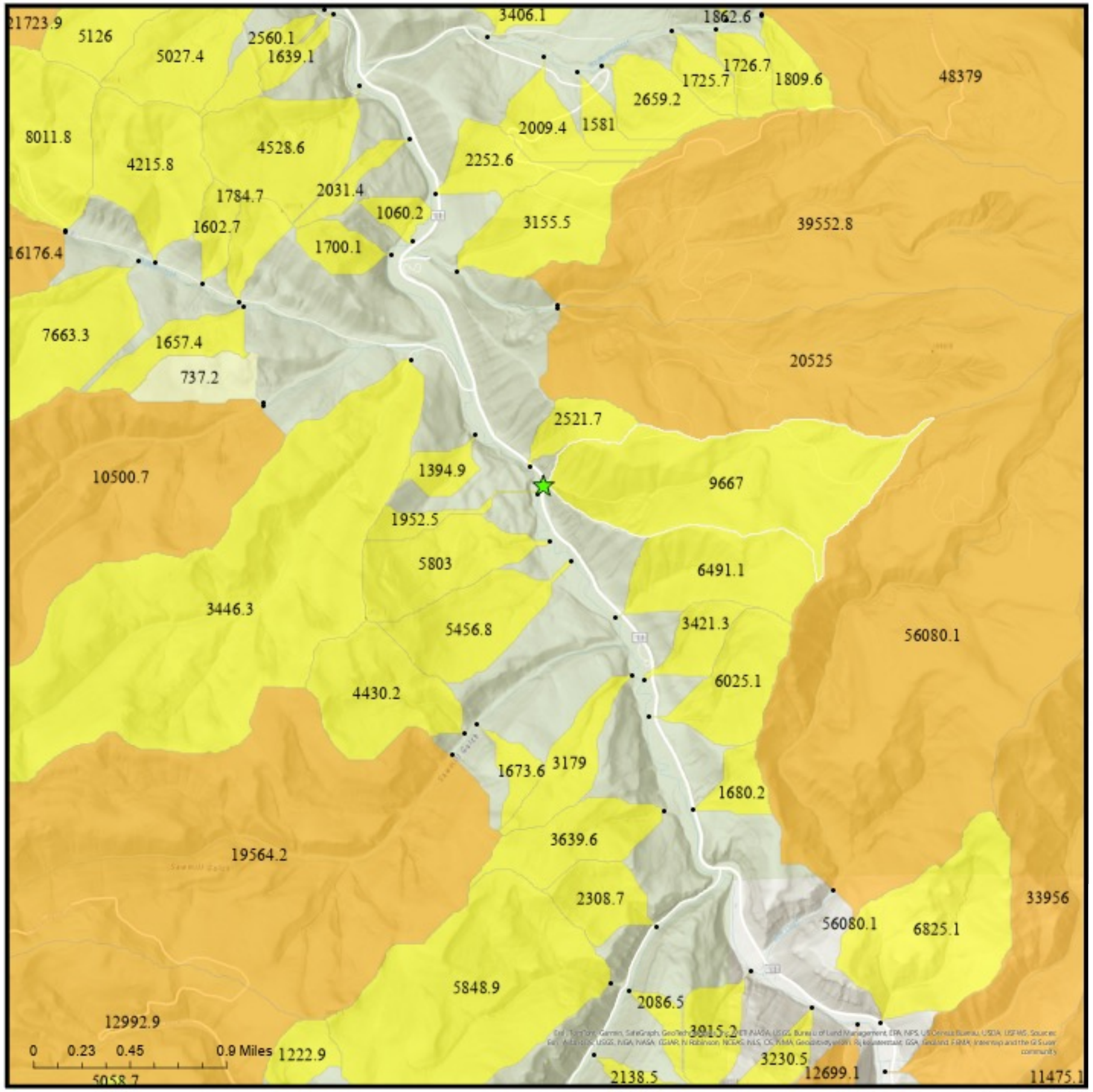
Which design storm?

32 mm/h

Debris-flow Likelihood

P (Likelihood)	0.76
PCI (Classification)	4
PCI_Legend	60-80%

How will this map change with less intense rainfall? More intense rainfall?



Volume (m³)

	<1,000
	1,000 - 10,000
	10,000 - 100,000

Volume

Basin-scale

Which design storm?

32 mm/h

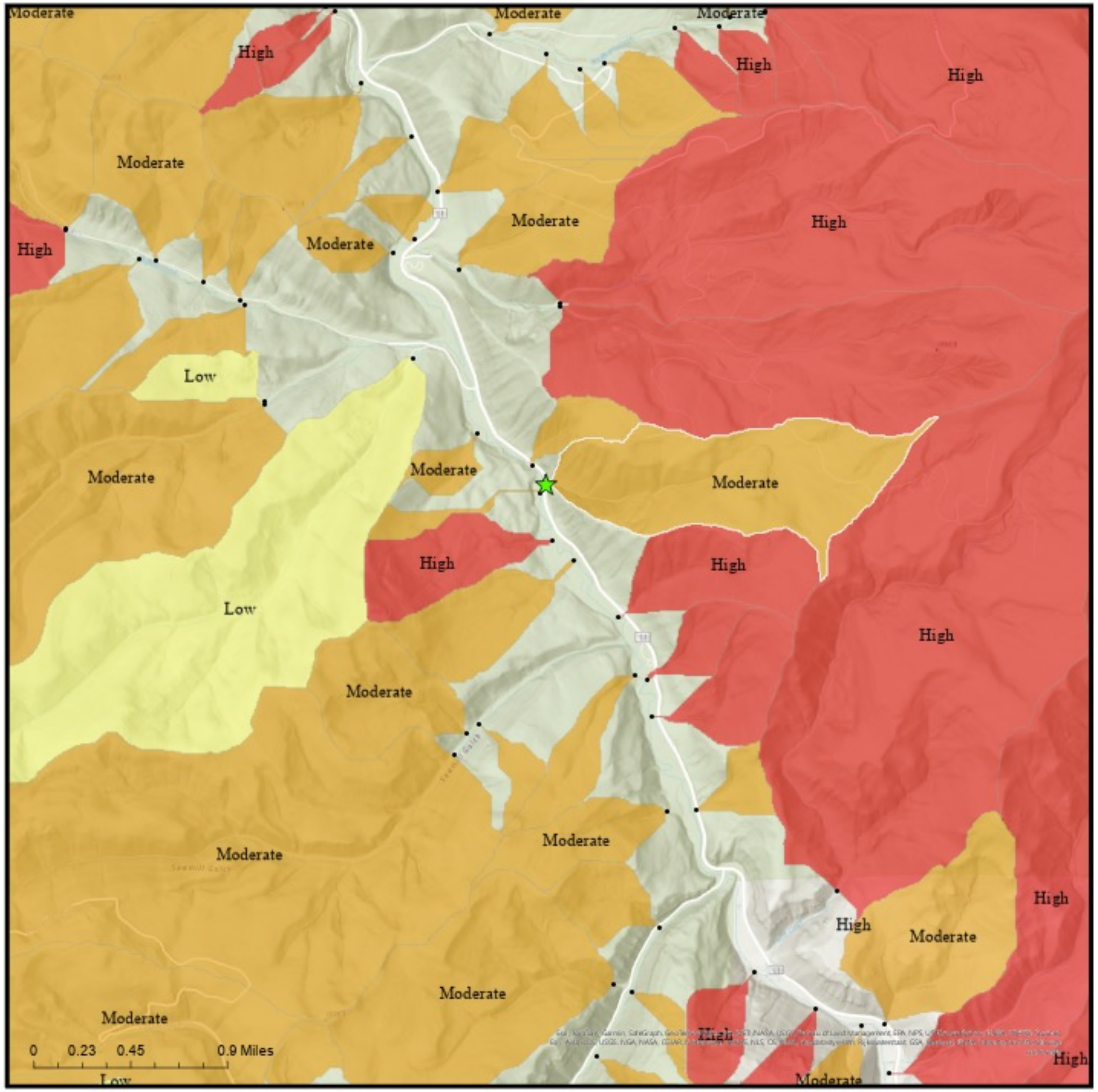
How will this map change with less intense rainfall? More intense rainfall?

Debris-flow Volume

Volume	9667
VolMin	1207
VolMax	77,379
VolCl	2
VolCl_Legend	1,000-10,000

Volume Range

1,207-77,379 m^3



Combined Hazard

Basin-scale

Which design storm?

32 mm/h

How will this map change with less intense rainfall? More intense rainfall?

	< 1,000	1,000 - 10,000	10,000 - 100,000	> 100,000
0 - 20%	Low	Low	Moderate	Moderate
20 - 40%	Low	Moderate	Moderate	Moderate
40 - 60%	Moderate	Moderate	Moderate	High
60 - 80%	Moderate	Moderate	High	High
80 - 100%	Moderate	High	High	High

East Troublesome Burn Area – July 2021

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Rainfall Thresholds

*Rainfall conditions that when **met or exceeded** a debris flow is likely to occur*

Support Early Warning

* At 347 PM MDT, Doppler radar indicated thunderstorms producing heavy rain over the Grizzly Creek Burn Area. Between 0.1 and 0.3 inches of rain have fallen. The expected rainfall rate is 0.5 to 1 inch in 1 hour. Additional rainfall amounts of 0.1 to 0.3 inches are possible in the warned area. Flash flooding is ongoing or expected to begin shortly.

Excessive rainfall over the burn scar will result in debris flow. The debris flow can consist of rock, mud, vegetation and other loose materials.

Rainfall Thresholds

Modeled

Terrain Steepness (T) + Fire Severity (F) + Soil Properties (S) = Rainfall (R)

Solved for various debris-flow probabilities

- We report the rainfall intensity that has a *50% likelihood* of producing debris flows
- Year 1 and Year 2 Thresholds
- Durations: 15-, 30-, and 60-minute
- Accumulation and Intensity
- Firewide and site-specific thresholds

Geomorphology 278 (2017) 149–162

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

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Prediction of spatially explicit rainfall intensity–duration thresholds for post-fire debris-flow generation in the western United States

CrossMark

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ARTICLE INFO

Article history:
Received 4 May 2016
Received in revised form 4 October 2016
Accepted 10 October 2016
Available online 14 October 2016

Keywords:
Wildfire
Debris flow
Rainfall thresholds
Hazard assessment

ABSTRACT

Early warning of post-fire debris-flow occurrence during intense rainfall has traditionally relied upon a library of regionally specific empirical rainfall intensity–duration thresholds. Development of this library and the calculation of rainfall intensity-duration thresholds often require several years of monitoring local rainfall and hydrologic response to rainstorms, a time-consuming approach where results are often only applicable to the specific region where data were collected. Here, we present a new, fully predictive approach that utilizes rainfall, hydrologic response, and readily available geospatial data to predict rainfall intensity–duration thresholds for debris-flow generation in recently burned locations in the western United States. Unlike the traditional approach to defining regional thresholds from historical data, the proposed methodology permits the direct calculation of rainfall intensity–duration thresholds for areas where no such data exist. The thresholds calculated by this method are demonstrated to provide predictions that are of similar accuracy, and in some cases outperform, previously published regional intensity–duration thresholds. The method also provides improved predictions of debris-flow likelihood, which can be incorporated into existing approaches for post-fire debris-flow hazard assessment. Our results also provide guidance for the operational expansion of post-fire debris-flow early warning systems in areas where empirically defined regional rainfall intensity–duration thresholds do not currently exist.

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1. Introduction

Over the past several decades, the frequency of large wildfires, length of fire season, and duration of individual wildfires have steadily increased in the western United States as a result of a combination of human activities, evolving land-use patterns, weather, and climate (Westerling et al., 2006). An increase in the susceptibility to debris flow is a secondary effect of wildfire in recently burned steeplands, a hazard which may persist for several years following fire containment (Cannon and DeGraff, 2009; Cannon et al., 2010; DeGraff et al., 2015). Risk associated with debris-flow hazards increases as populations expand into foothill and mountainous areas susceptible to wildfire. In addition, a greater incidence of fire activity in mountainous areas with relatively infrequent fire recurrence may increase the potential of debris flows in environments or communities where debris-flow hazard has been historically absent (Cannon and DeGraff, 2009). The geographic expansion of areas exposed to post-fire debris-flow hazard has motivated efforts to reduce exposure of people, infrastructure, and important natural, cultural, and economic resources to these hazards. Hazard assessment provides the first step in reducing public exposure to these events, as this process identifies areas vulnerable to post-fire debris-flow generation, and provides estimates of the magnitude of an event, should one occur (Cannon et al., 2008, 2010, 2011; Staley et al., 2013a, 2013b, 2013c).

In the western United States, the most common methods for post-fire debris-flow hazard assessment are based upon statistical models that predict the likelihood and magnitude of debris flow for a specific location using historical data (Gartner et al., 2008, 2014; Cannon et al., 2010). These hazard assessments (e.g. Cannon et al., 2009; Parise and Cannon, 2012; USGS, 2016) are useful for identifying and prioritizing areas of potential debris-flow hazard for planning purposes, but are not intended for direct predictive use in early warning systems (Cannon et al., 2010). Instead, post-fire debris-flow early warning in the western United States relies upon regionally specific rainfall intensity–duration thresholds (Cannon et al., 2008, 2011; Staley et al., 2013b, 2015). Regional thresholds are determined from historical data that characterize the rainfall intensities that produced, or did not produce, debris flows for specific locations. The empirical approach for establishing regional rainfall intensity–duration thresholds requires an extensive library of rainfall and basin response information from which the thresholds can be calculated by either subjective (e.g.

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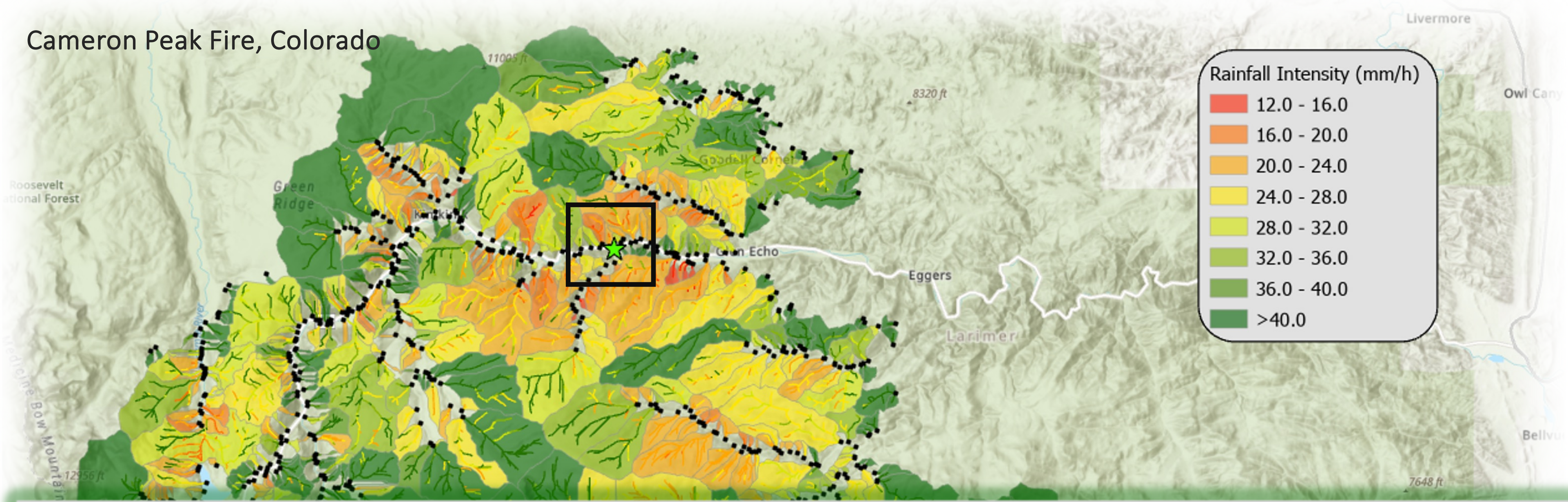
http://dx.doi.org/10.1016/j.geomorph.2016.10.019
0169-555X/Published by Elsevier B.V.

Rainfall Thresholds

Year 1 Firewide rainfall thresholds

Median value of all segments or basins thresholds in the burn area



Most of the burn area is estimated to have a moderate level of debris-flow hazard. Most stream reaches and watersheds are estimated to have a greater than 50% likelihood of producing debris flows at 15-minute rainfall intensities between 32 and 40 mmh-1. The east-facing watersheds on the east side of Sierra de Salinas, and the steep sub-catchments within the Tularcitos and Agua Mala watersheds are estimated as having higher likelihoods. Debris-flow magnitude is somewhat aspect-dependent, with watersheds on the eastern side of the burn area having volume estimates in excess of 10,000m^3, and those on the west side typically in the range of 1,000 – 10,000 m3. ***The model-estimated thresholds (basin-scale) are as follows:***

15-minute: 33 mm/h, or 0.3 inches in 15 minutes

30-minute: 26 mm/h, or 0.5 inches in 30 minutes

60-minute: 24 mm/h, or 1 inches in 60 minutes

Rainfall Thresholds

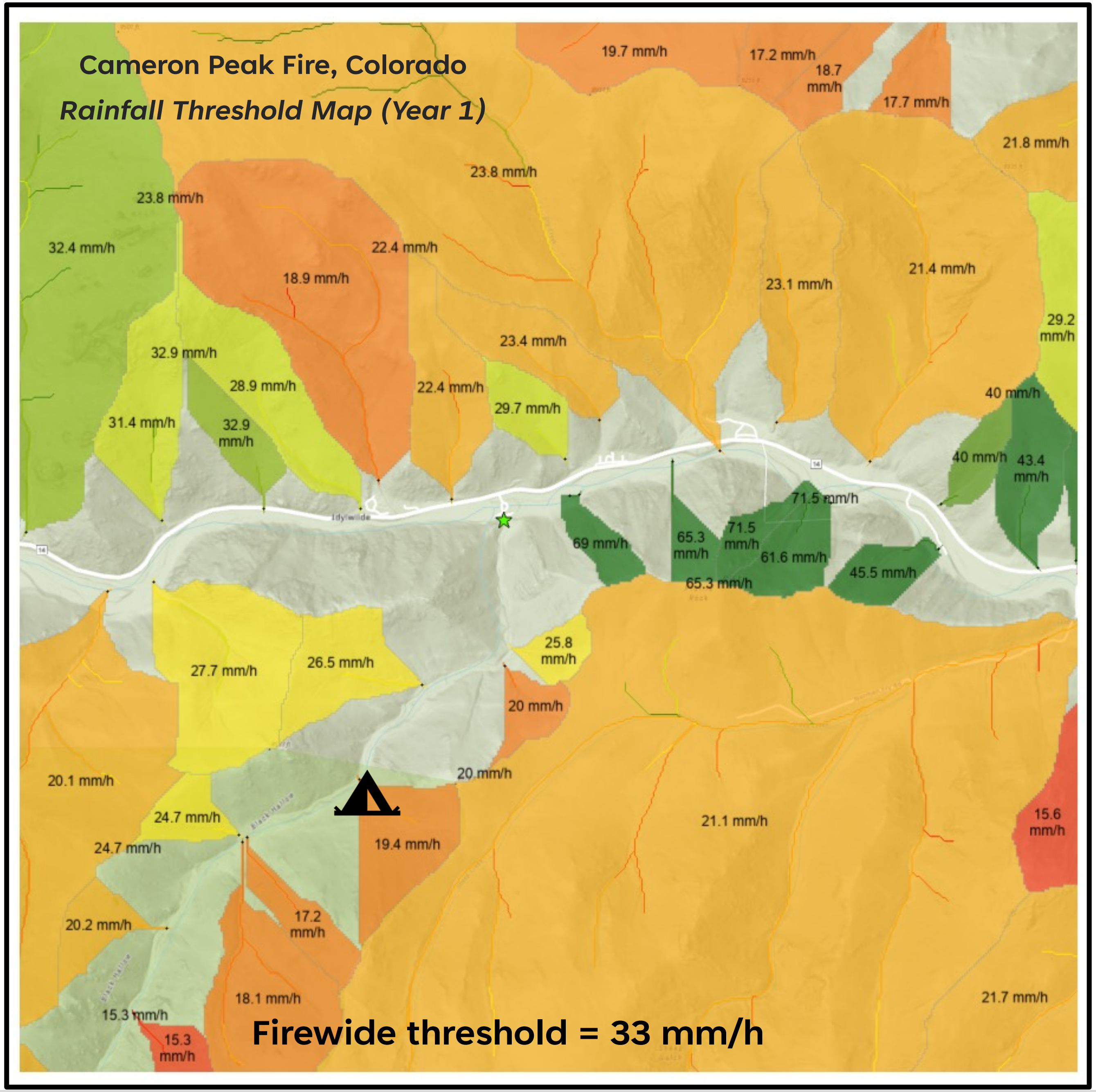
Year 1: Site-specific Thresholds

Site-specific thresholds can be considerably lower (more hazardous)

1. Predict the likelihood that a debris flow will occur at a given rainfall intensity for any stream segment or basin in the burn area

2. Help identify values at risk

NOAA Atlas 14
1 year recurrence interval storm = 33 mm/h



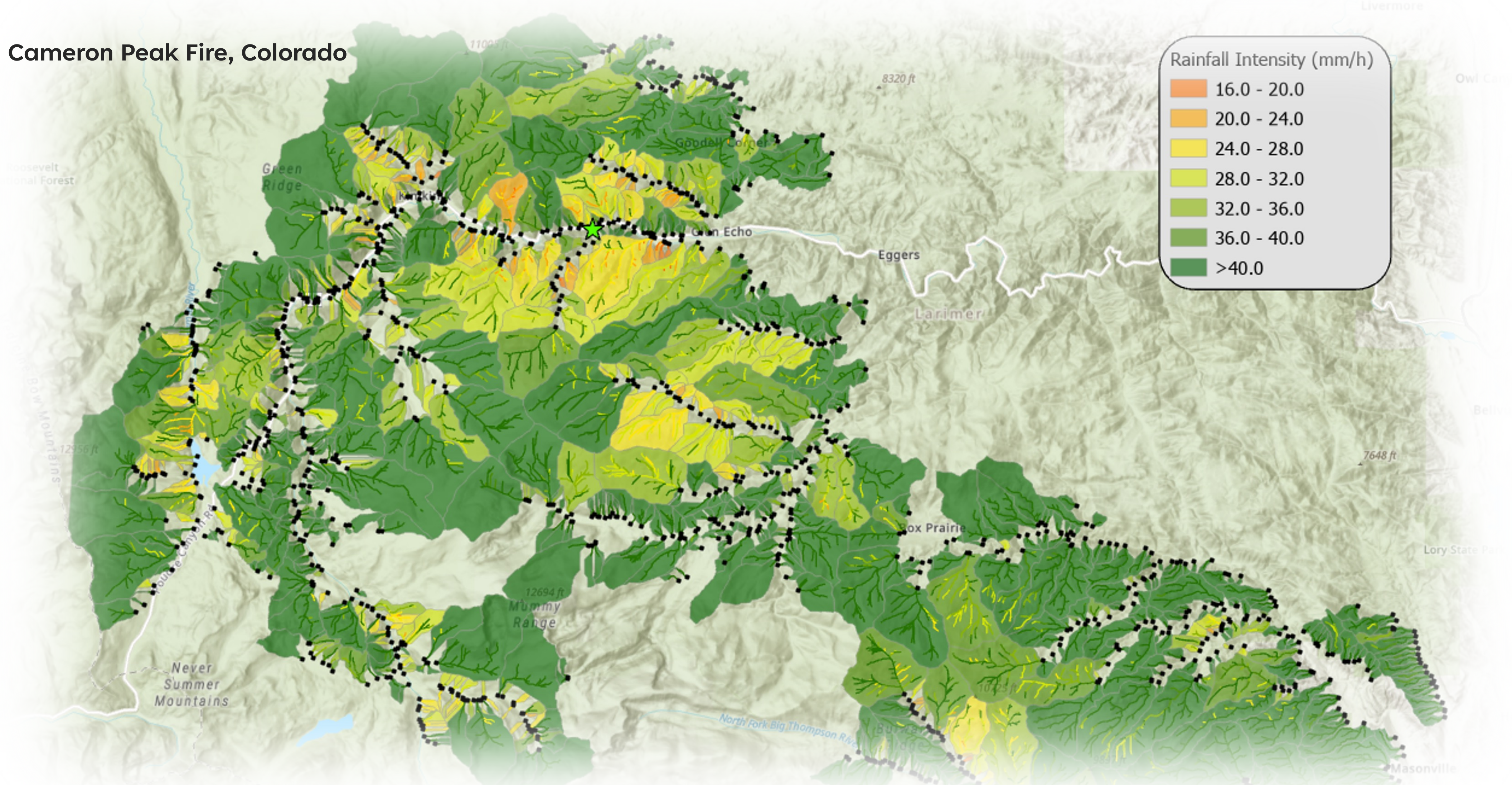
Cameron Peak Burn Area, July 2021

Peak 15-min rainfall intensity: 36-52 mm/h

Rainfall Thresholds

Year 2: Firewide Thresholds

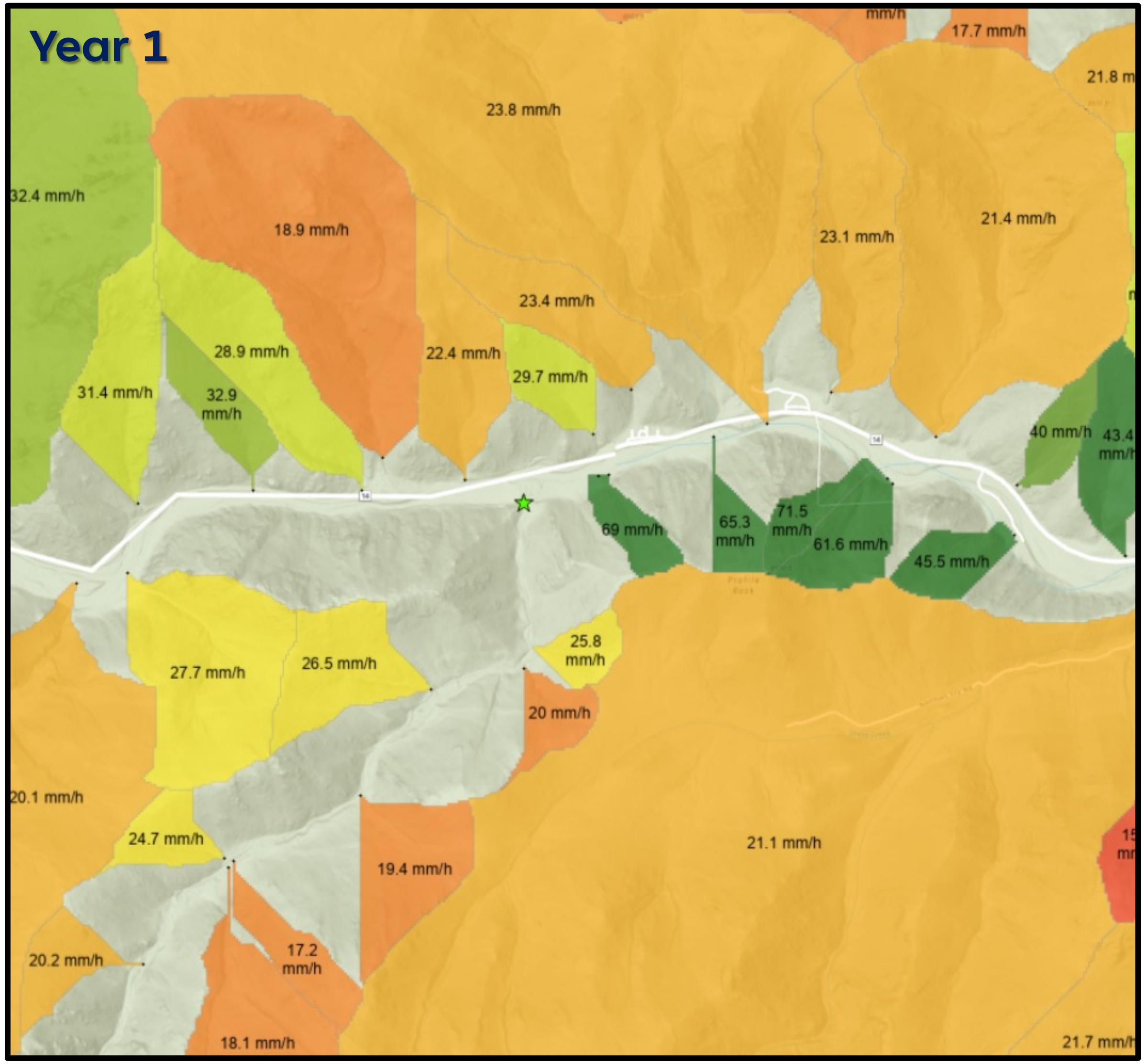
Thresholds change over time as the burn area recovers

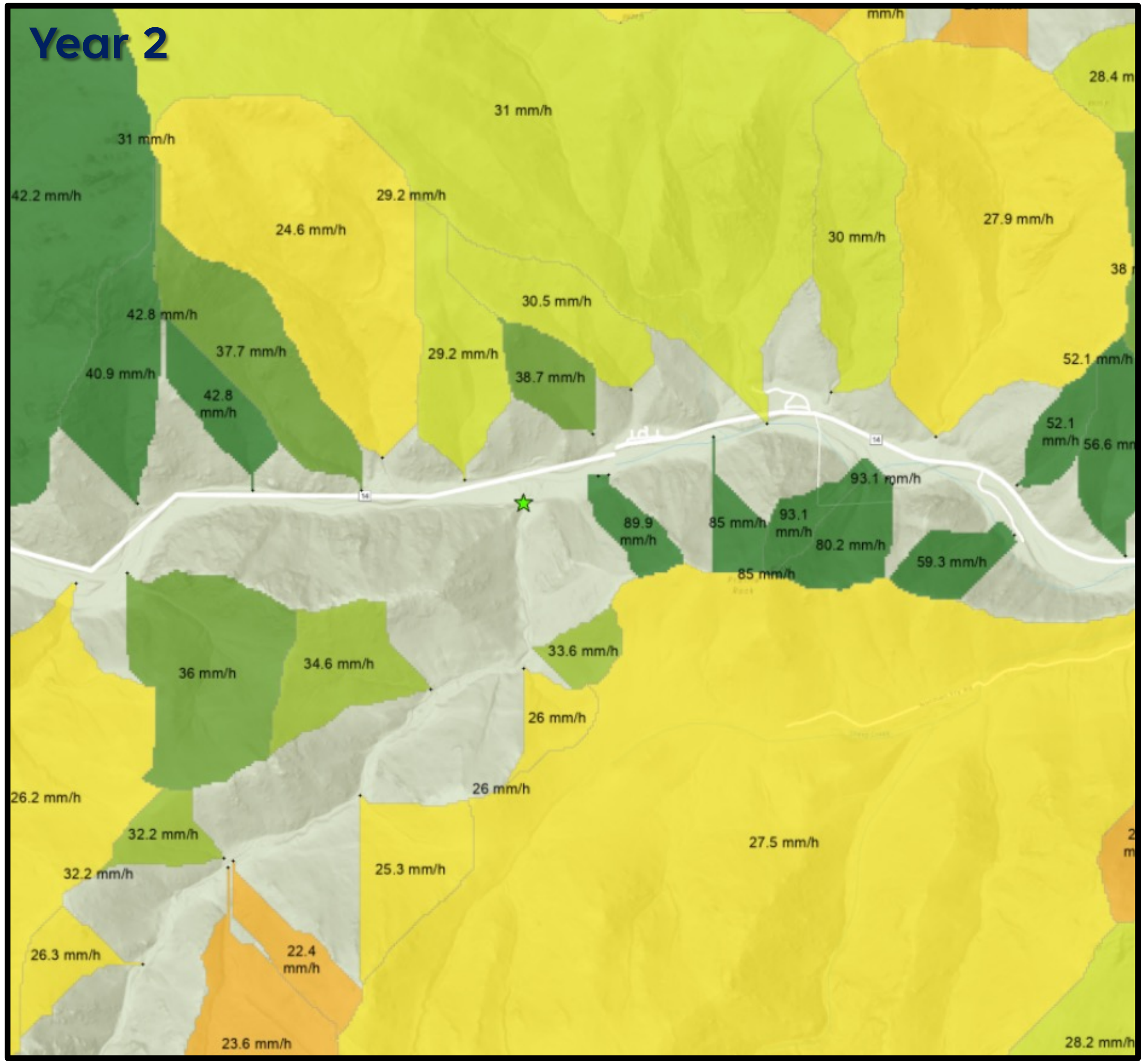


Rainfall Thresholds

Cameron Peak burn area

Site-specific





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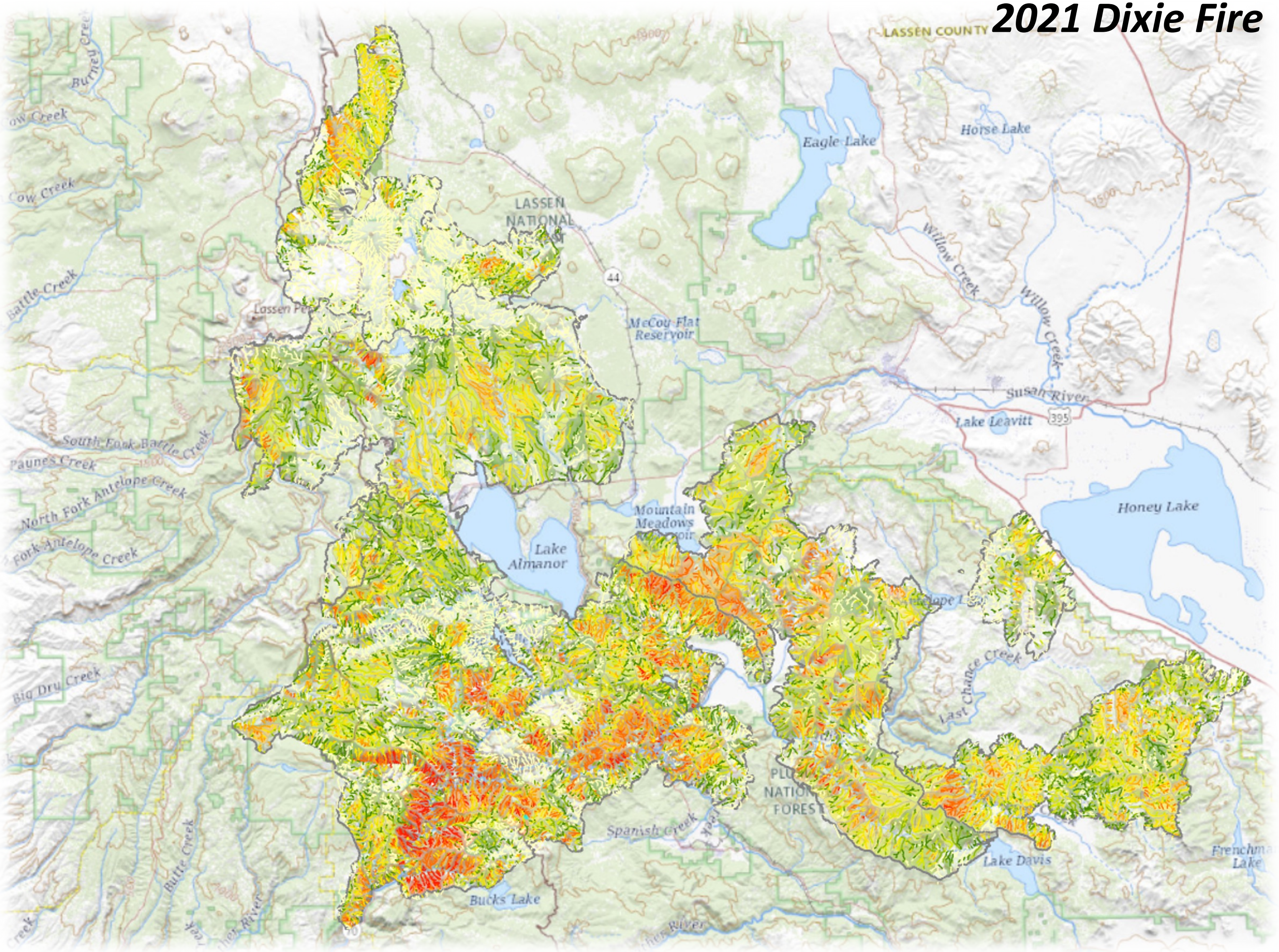
Can you think of challenges with using rainfall thresholds?

- Difficult for forecasting
- Spatial variability of intense rainfall
- Large fires may span precipitation regimes

2021 Dixie Fire



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Model Limitations

Accessing the Data

How do I access the data?

Data download

USGS Post Wildfire Debris Flow Hazard Assessment Viewer

Select Fire Year	Select by Fire	State Filter
View All Fire Years	East Troublesome	View All

Fires Within Map Extent

(Select to View Details)

Calwood Fire
Arapaho and Roosevelt National Forests, CO
Start Date: October 16, 2020

Cameron Peak Fire
Arapaho and Roosevelt National Forests, CO
Start Date: August 12, 2020

Cold Springs Fire
Nederland, CO
Start Date: July 8, 2016

East Troublesome Fire
Arapaho and Roosevelt National Forests, CO
Start Date: October 13, 2020

Alphabetical | Most Recent

1 of 6

Download Hazard Assessment Results

East Troublesome

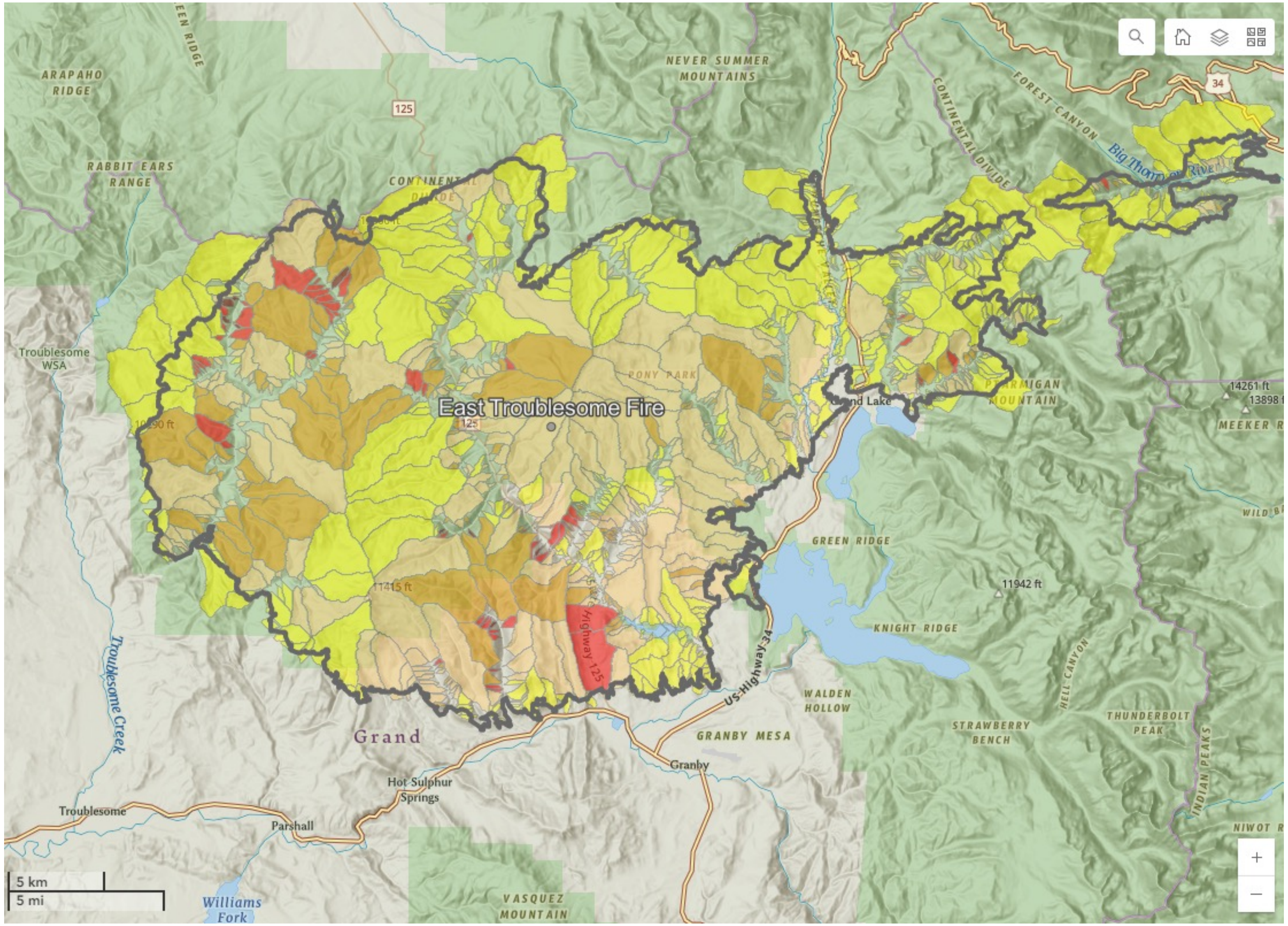
Hazard Assessment Data

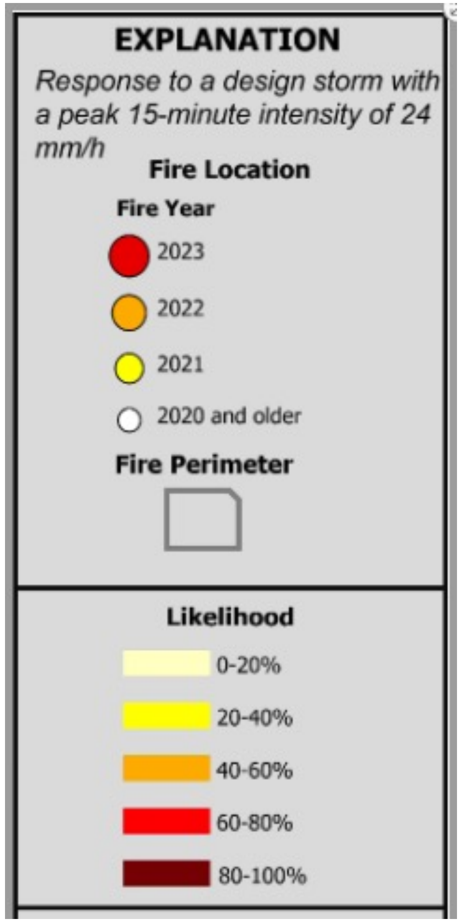
Geodatabase Download Link	View
Shapefile Download Link	View
Hazard Assessment PDF	View
Unique URL	https://usgs.maps.arcgis.com/apps/dashboards/c09fa874362e48a9afe79432f2efe6fe#fire=East Troublesome

How do I access the data?

Data download

Basins and segments – Debris-flow Likelihood





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Hazard Assessment Code

King, J., 2023, pfdf - Python library for post-fire debris-flow hazard assessments and research, version 1.0.0: U.S. Geological Survey software release, https://doi.org/10.5066/P9JO58MJ [JONATHAN KING - PREFIRE PLANNING SESSION, WEDS 8:30am]

Model Calculations

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Rainfall Thresholds

Staley, D. M., Negri, J. A., Kean, J. W., Laber, J. L., Tillery, A. C., & Youberg, A. M. (2017). Prediction of spatially explicit rainfall intensity–duration thresholds for post-fire debris-flow generation in the western United States. *Geomorphology*, *278*, 149-162.

Recovery

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Thank you!

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Questions? Feedback?