

Postfire debris-flow hazard assessment

Assessing and understanding the data

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U.S. Geological Survey



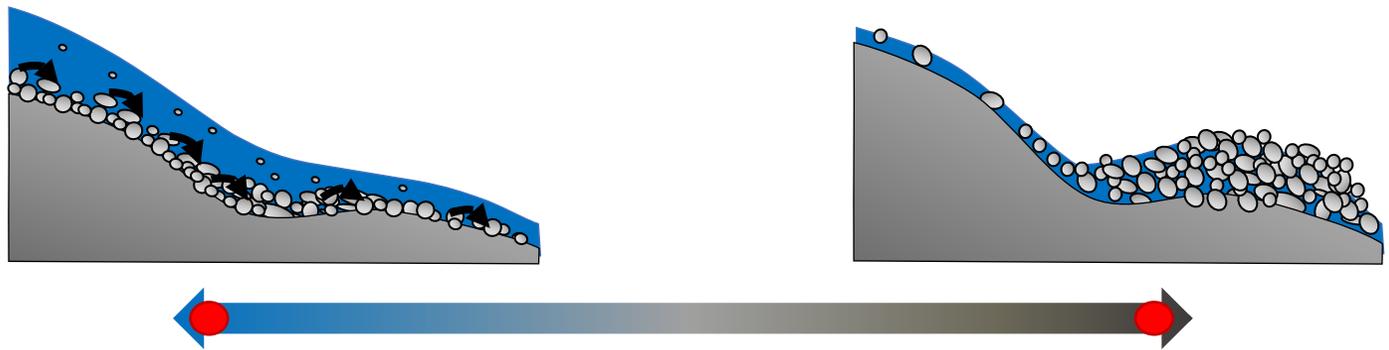
Outline

- 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:

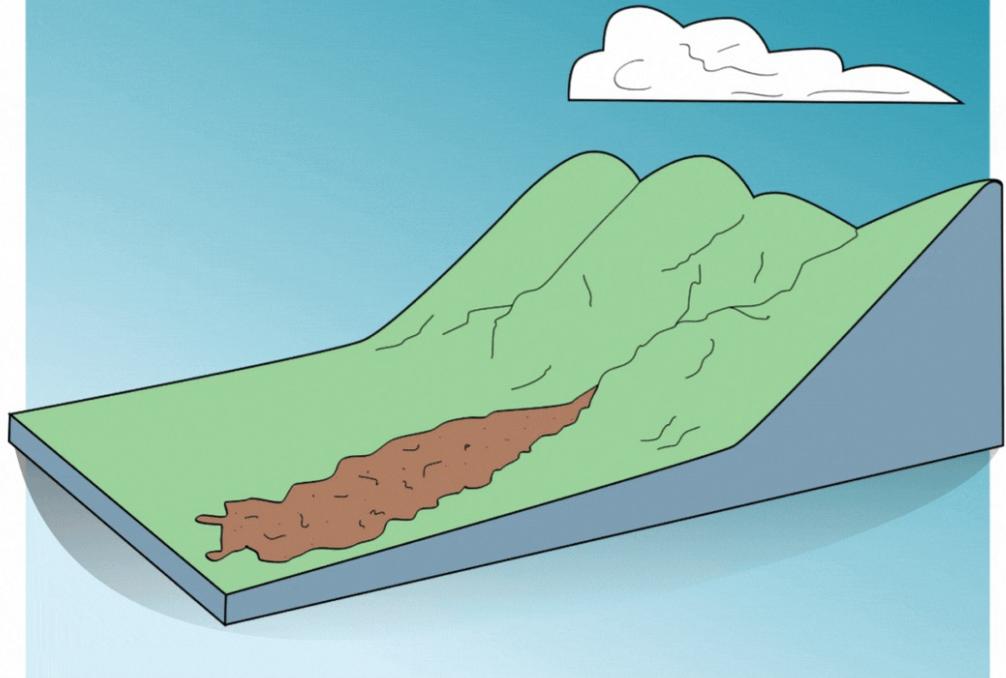
- Approximately 50% sediment
- Initiate from surface runoff and erosion processes.
- Progressive entrainment of sediment.
- Often exhibit evidence of both debris-flow and flood processes.



Water (Flood) flow and sediment transport *Flow Continuum* **Debris flow**

DEBRIS FLOW

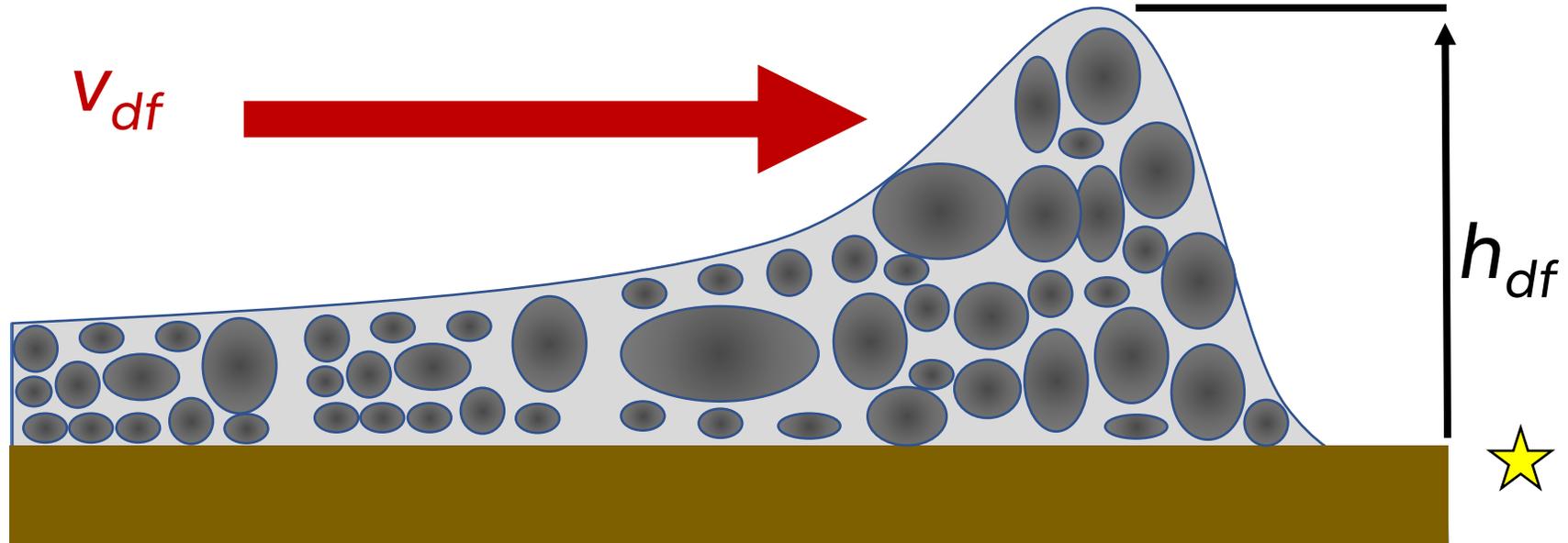
Rapidly moving mix of water, mud, trees, and other materials that flows downvalley and can travel great distances.



TYPES OF LANDSLIDES

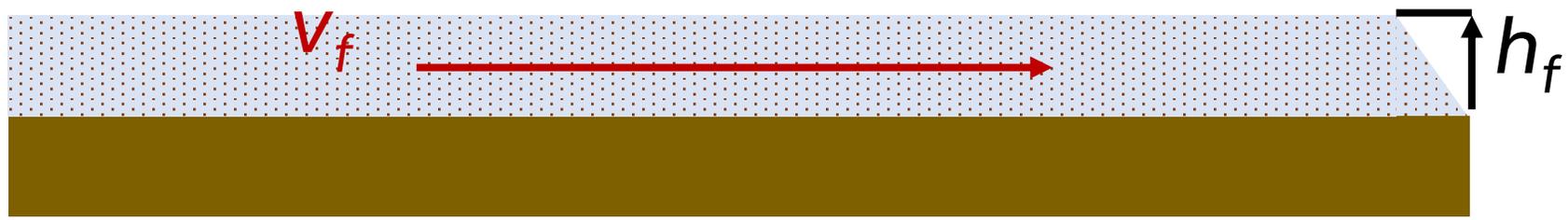


Debris flows are worse than flash floods



Debris Flow

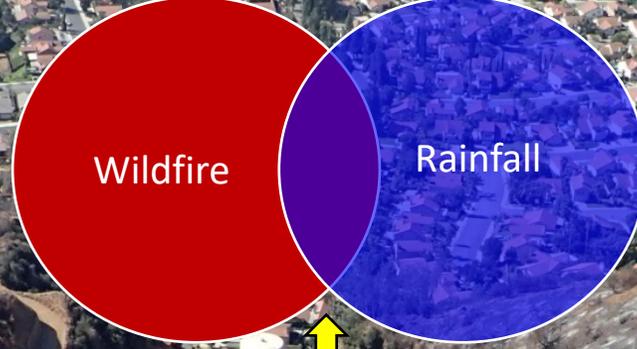
★ Flow height (h) up to 5x greater for debris flow



Flood

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

Wildfire increases the potential for runoff and erosion



DEBRIS FLOW



Reduces soil infiltration capacity



Makes soil more easy to erode

2016 Fish Fire
Duarte, Los Angeles County, CA



The June 2016 Fish Fire burned over 12 km² 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.

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



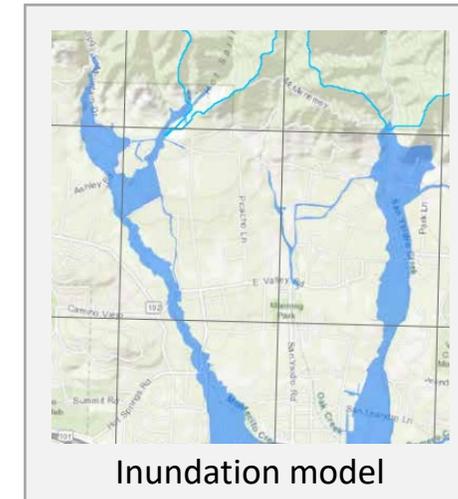
The watershed slope averages 30 degrees and is about 500 yards by 250 yards in dimension.

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

USGS Rapid assessment of debris-flow hazard

Under development

How fast/far?

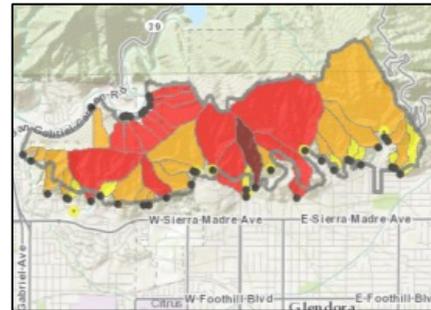


How long?



★ *Where?*

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



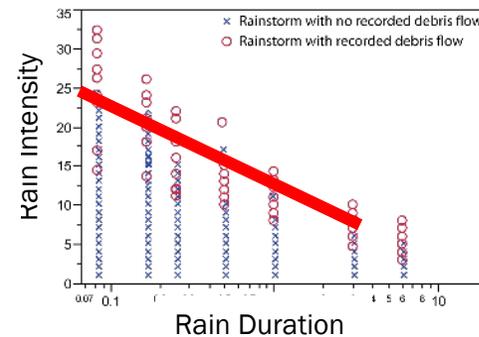
★ *How big?*

How much sediment can debris flows carry?



★ *When?*

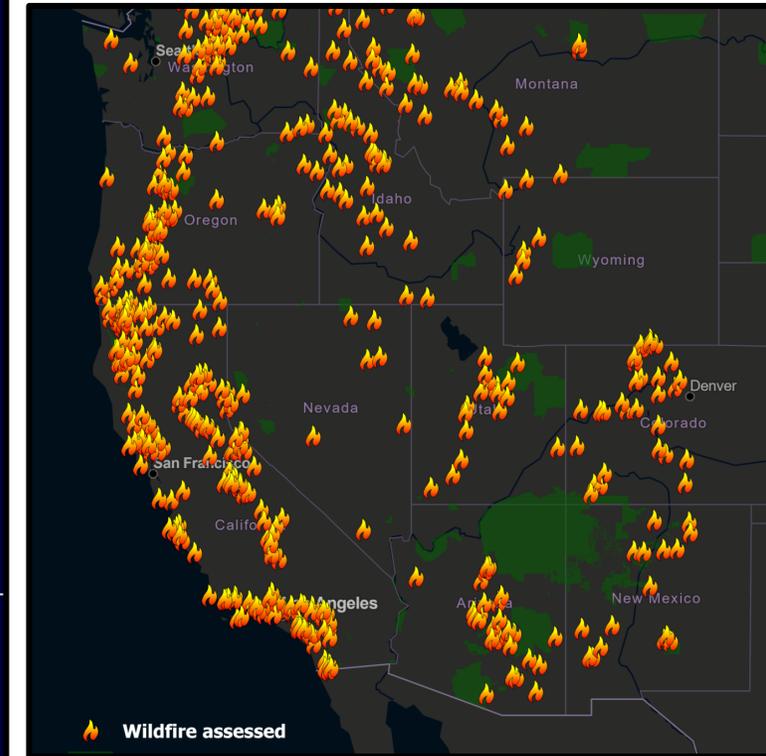
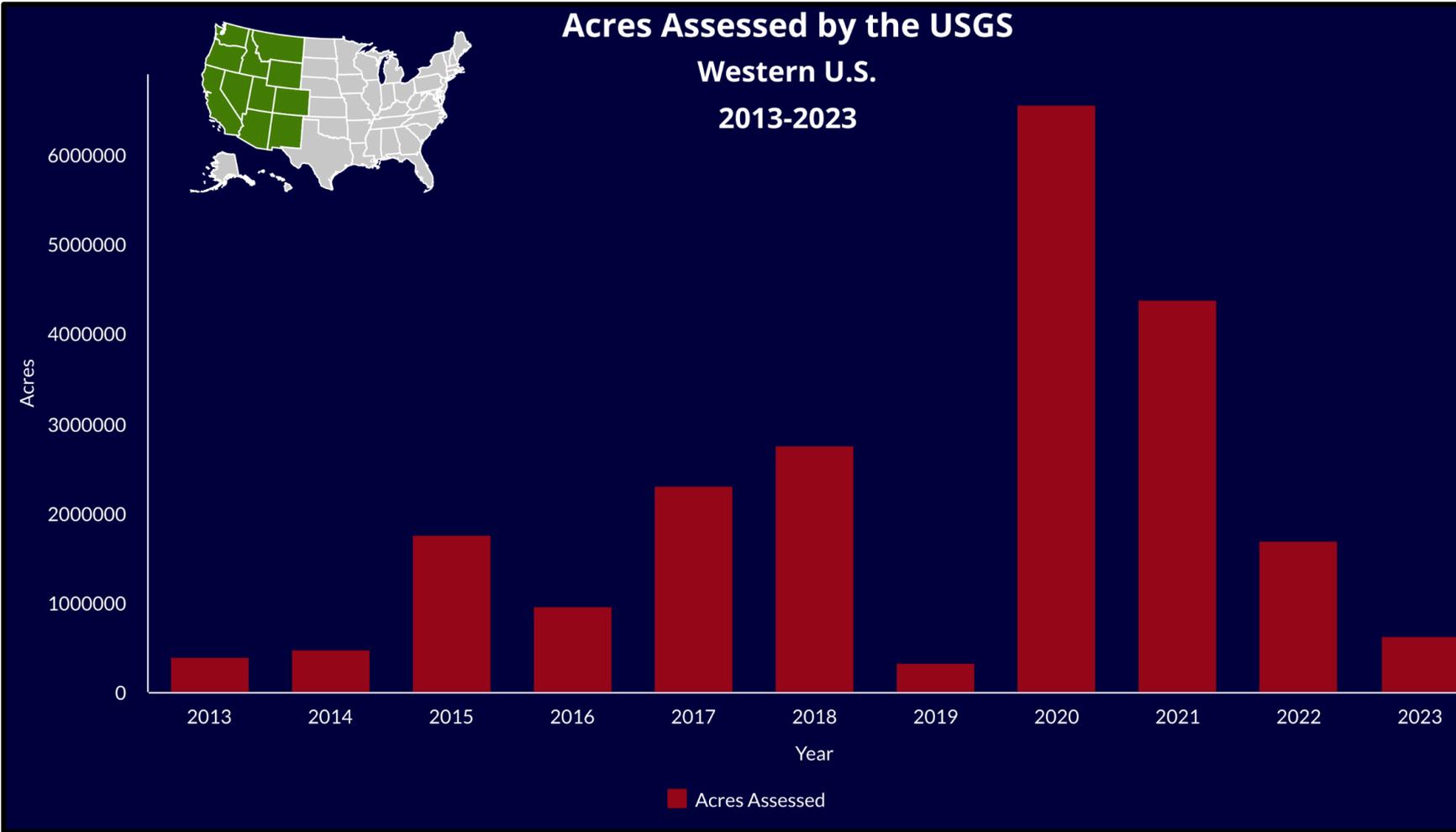
How hard must it rain to trigger debris flows?



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

USGS Hazards Assessment 2013-2023

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



USGS Hazard Assessments

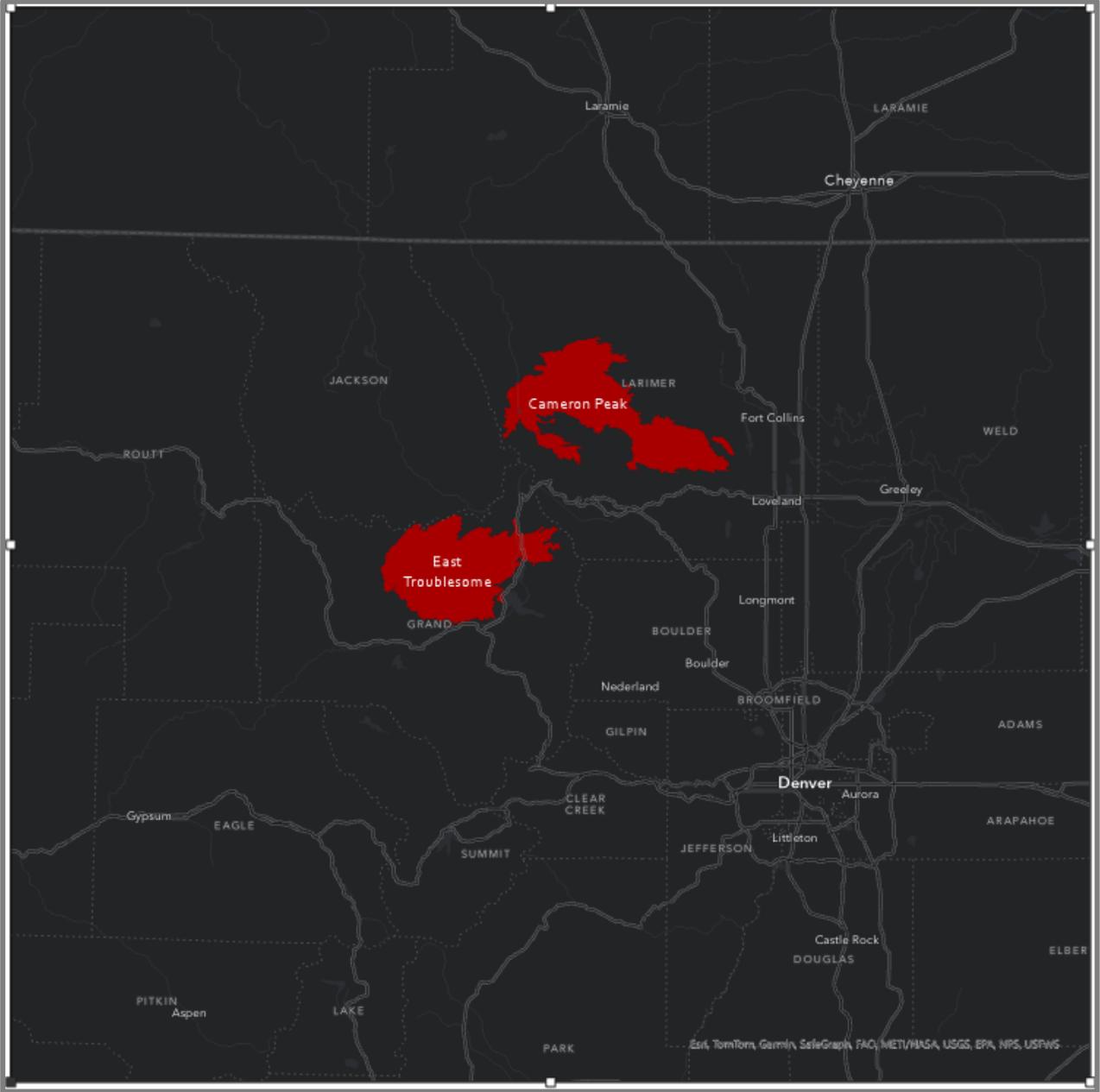
2020 Cameron Peak Fire, Arapahoe & Roosevelt NF
2020 East Troublesome Fire, Grand County, Colorado

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 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



BAER



WERT

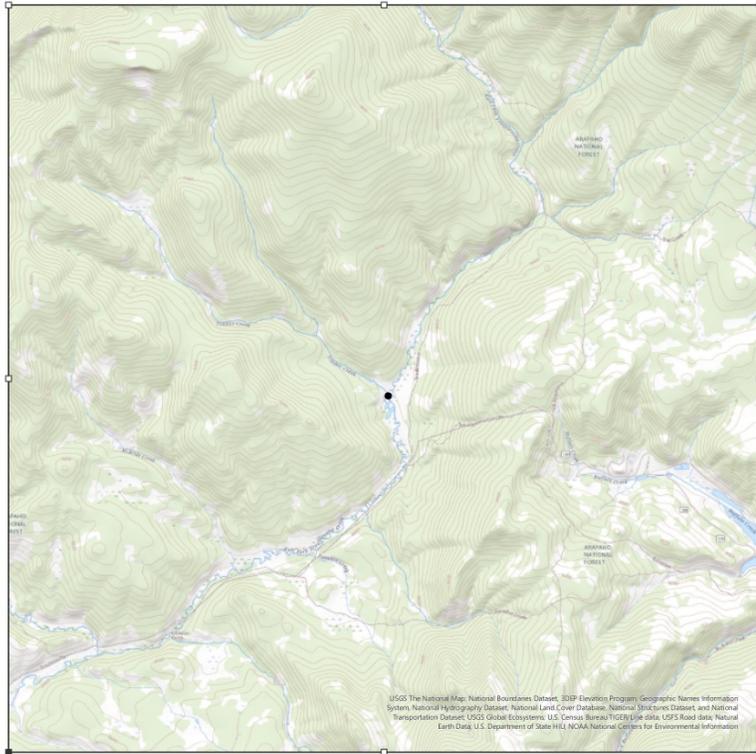
Modeling Steps

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

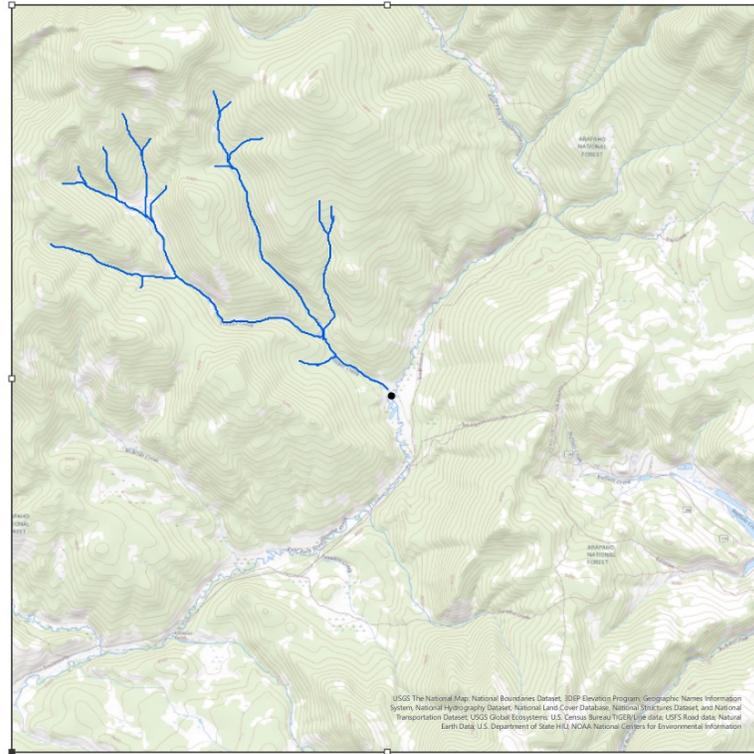
Building the watershed network

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

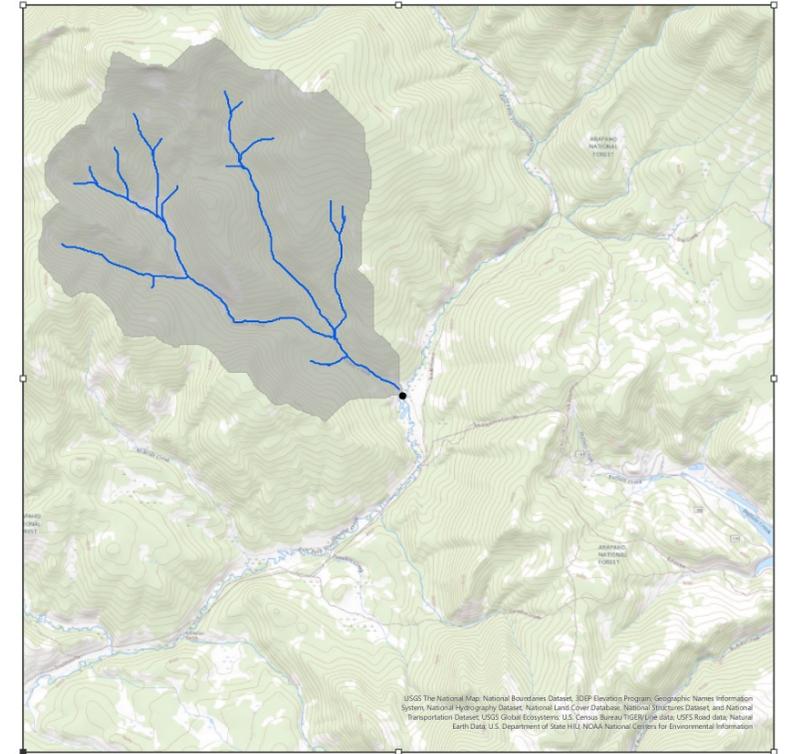
★ Criteria specific to debris flows



Basin outlet



Stream network



Drainage area

Stream reaches: 500 meters

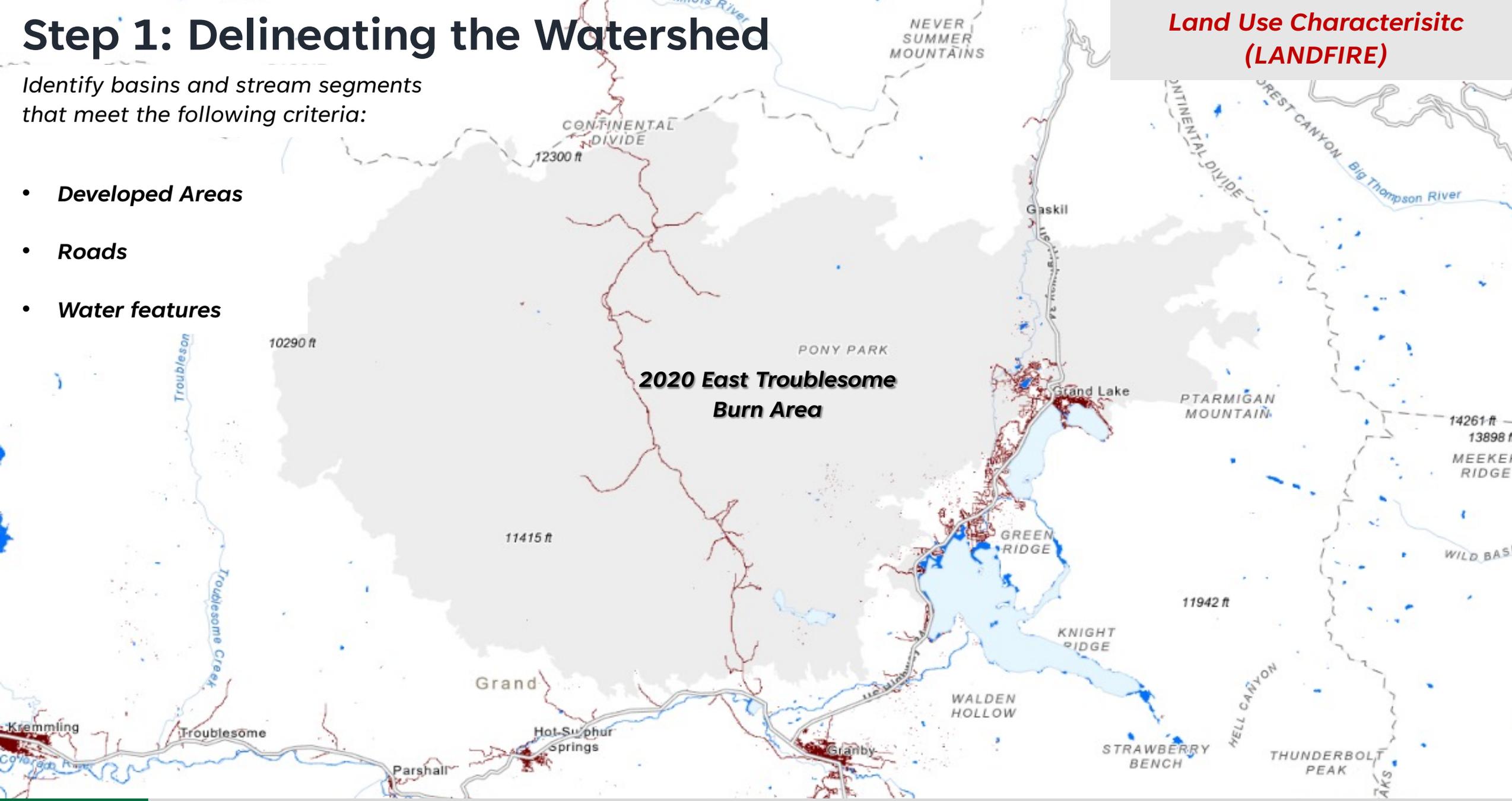
Basins: 0.25 to 8 km²

Step 1: Delineating the Watershed

Identify basins and stream segments that meet the following criteria:

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

Land Use Characteristic (LANDFIRE)

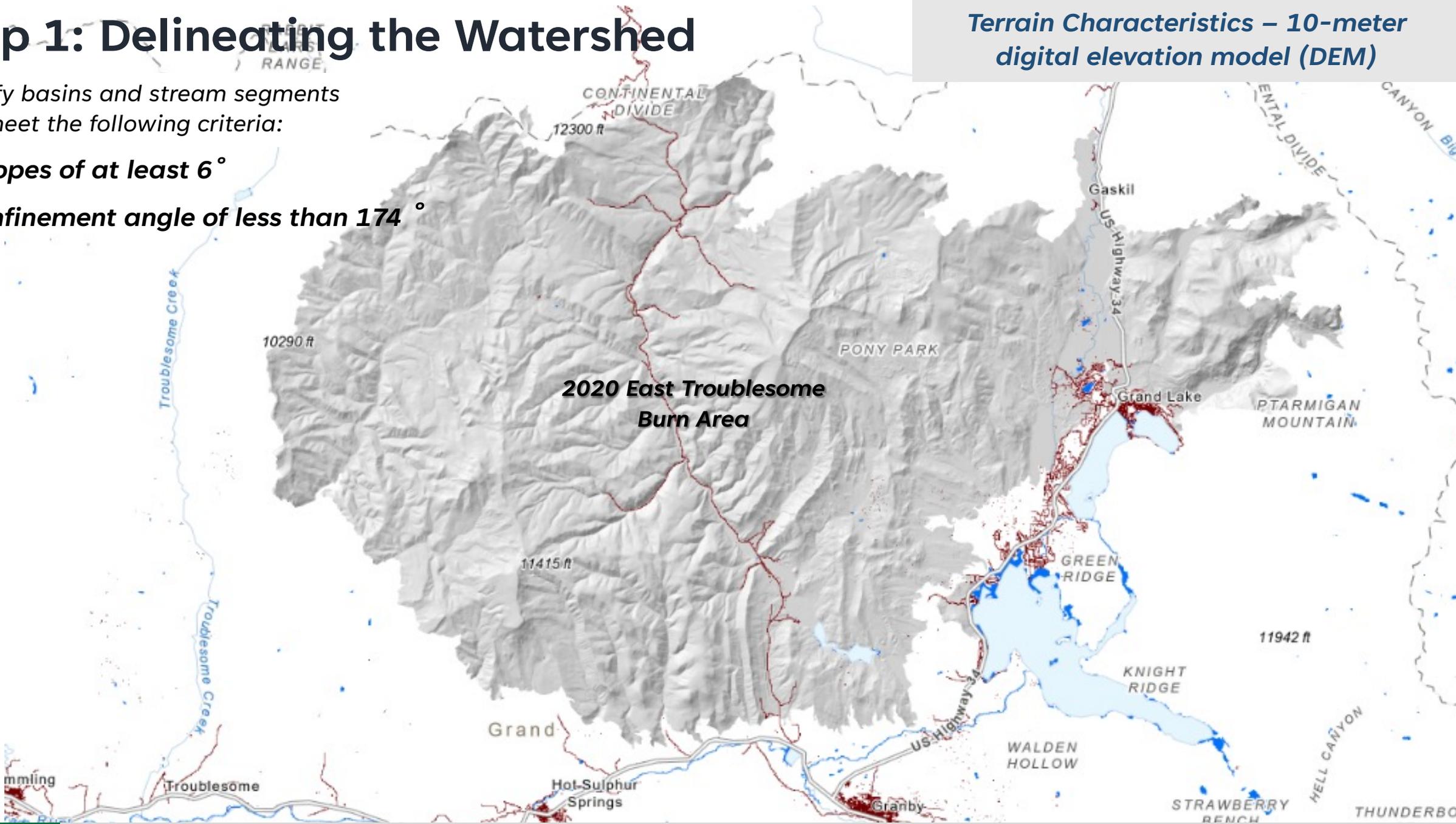


Step 1: Delineating the Watershed

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°



Example watershed

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

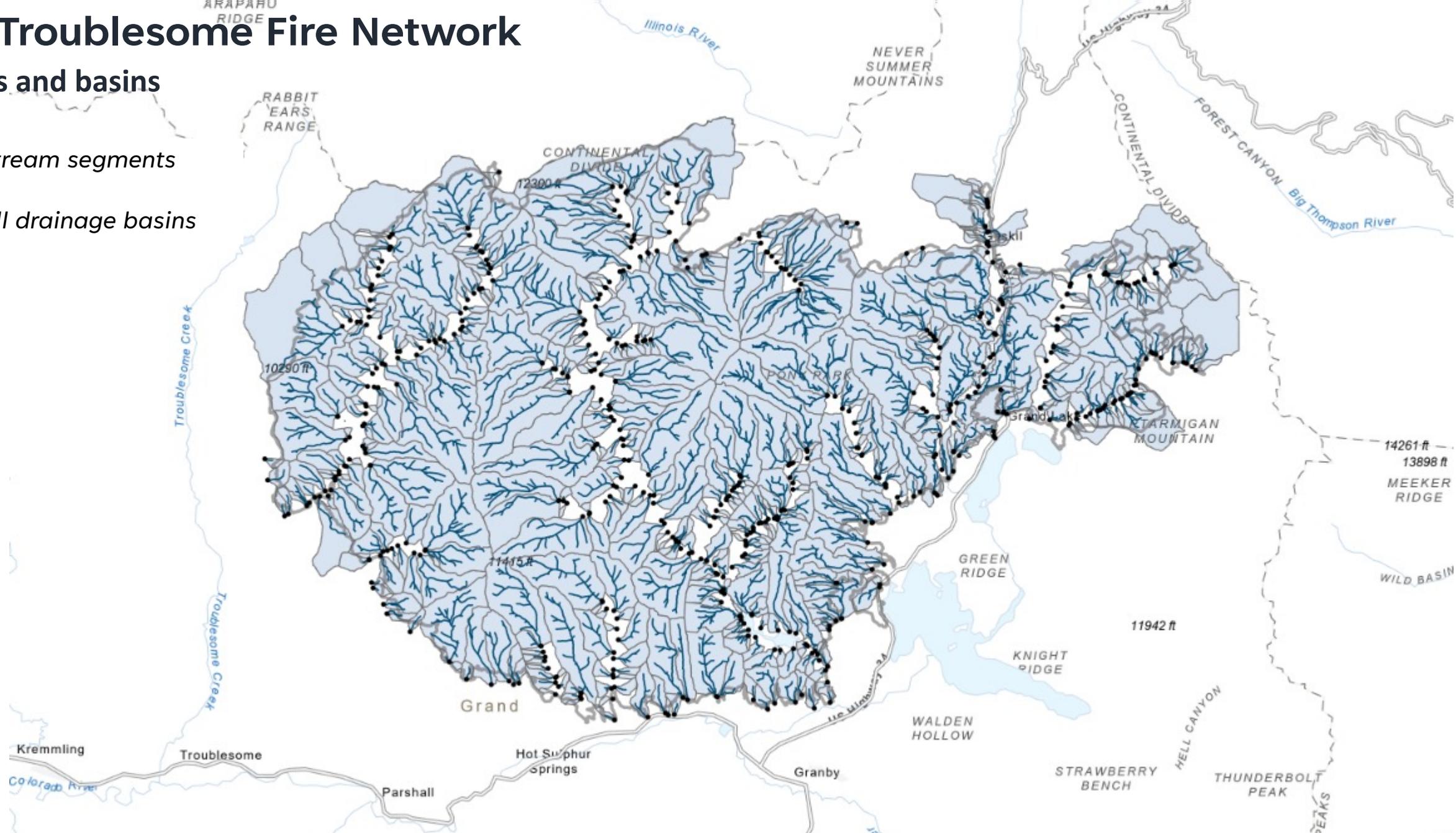


East Troublesome Fire Network

Streams and basins

10,000 Stream segments

578 Small drainage basins

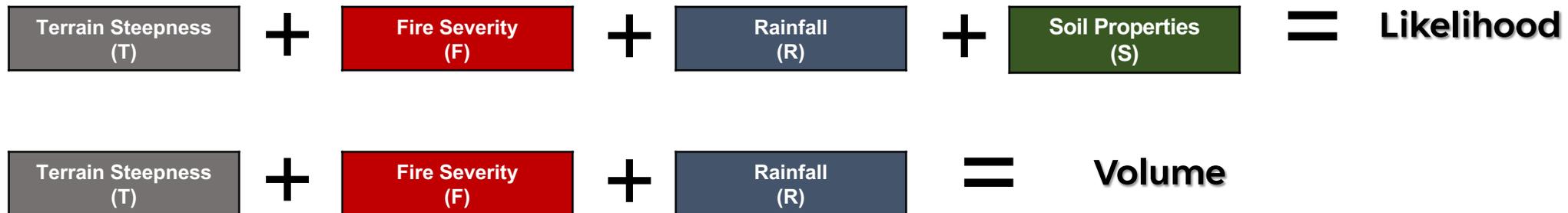


Calculating the Hazard

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

- ~~Fire perimeter~~
- ~~Terrain Data (DEM)~~
- ~~Land Use Data~~
- **Fire Severity – BAER TEAM**
- **Soils Data**
- **Rainfall**

Model Inputs



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

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

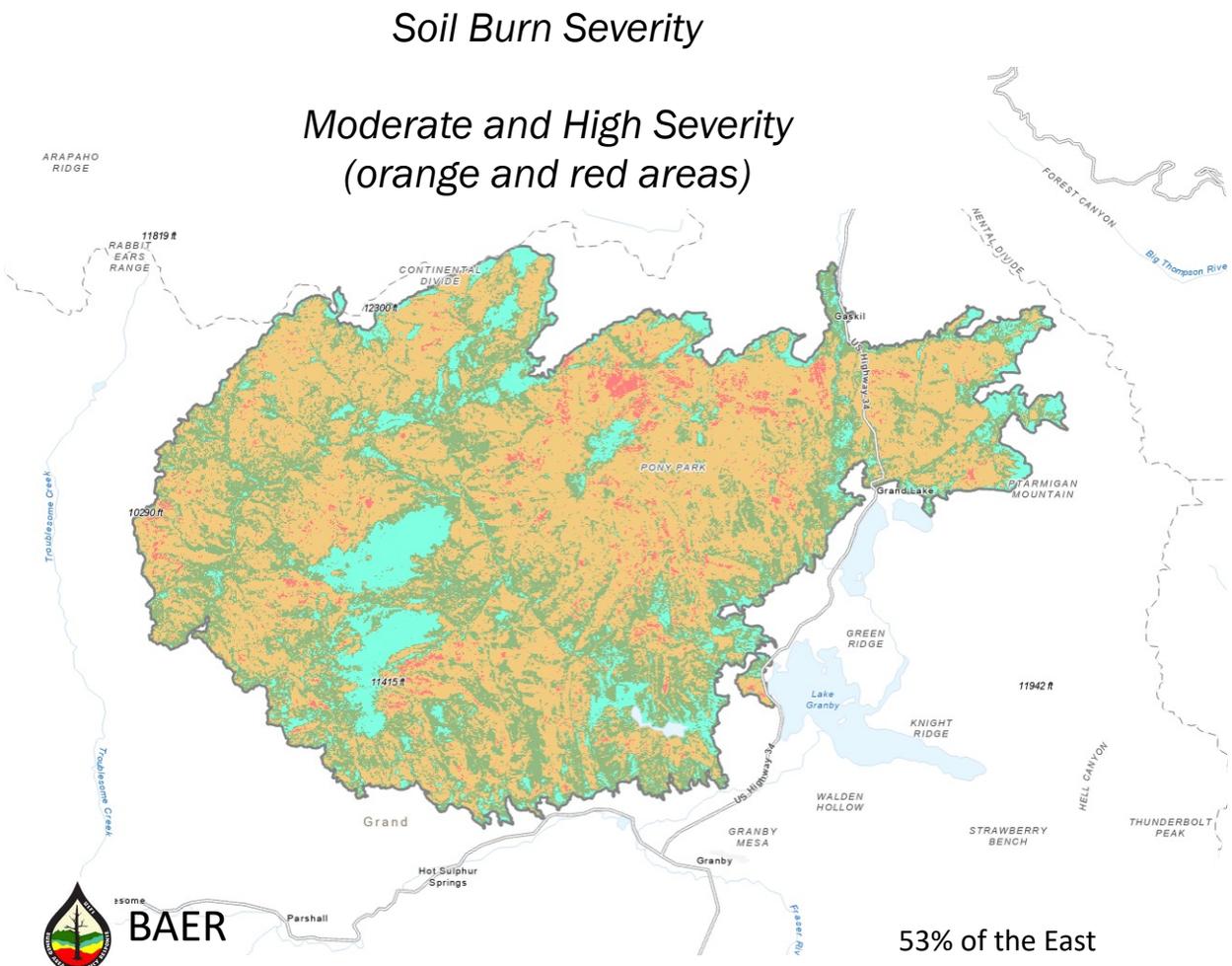
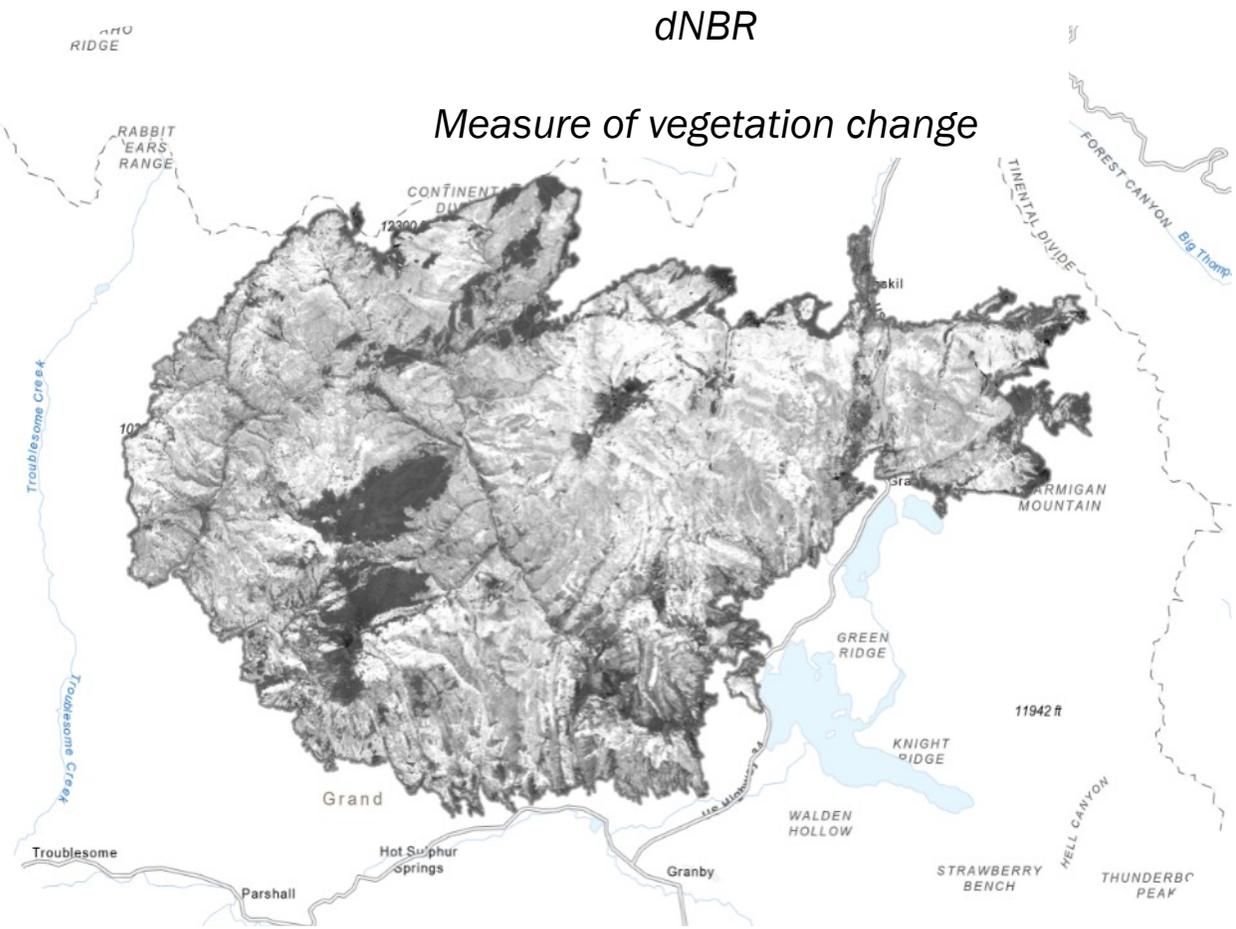


Empirical models for predicting volumes of sediment deposited by debris flows and sediment-laden floods in the transverse ranges of southern California

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

Calculating the Hazard

Burn Severity



BAER



WERT

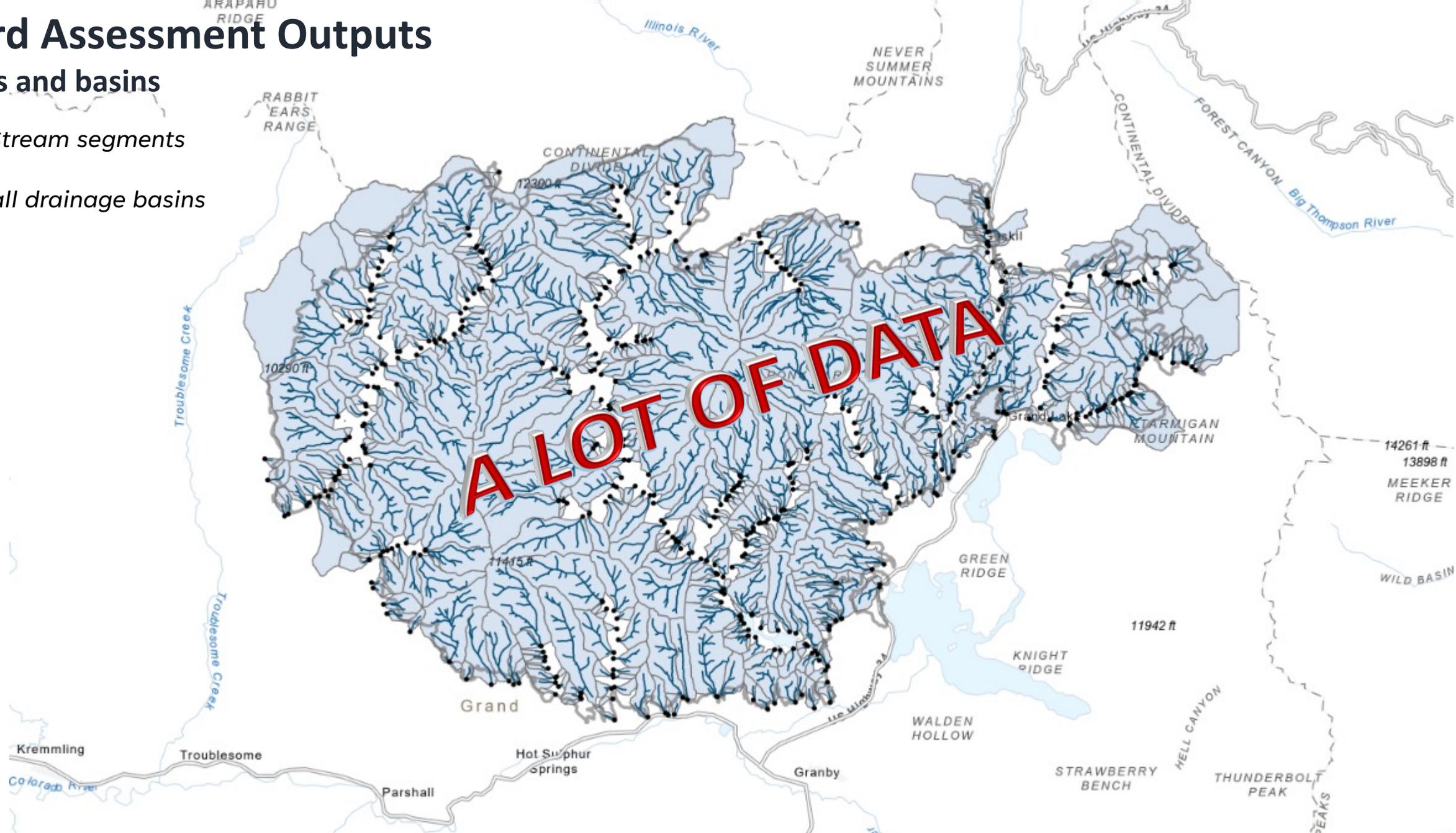
53% of the East Troublesome area is burned at high and moderate severity

Hazard Assessment Outputs

Streams and basins

10,000 Stream segments

578 Small drainage basins

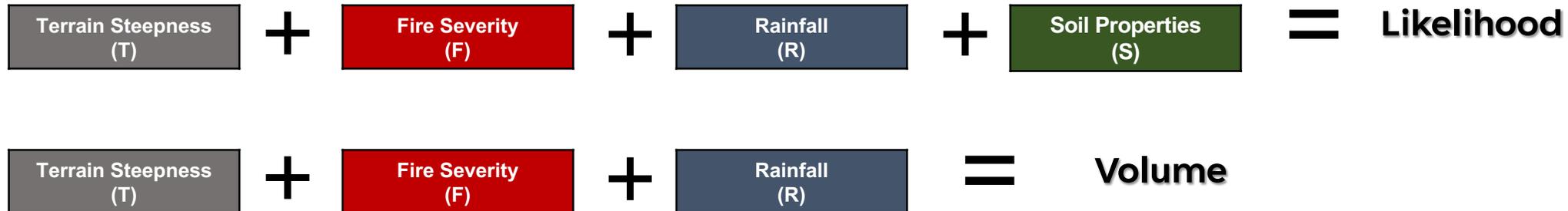


Calculating the Hazard

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

- ~~Fire perimeter~~
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- **Soils Data**
- **Rainfall**

Model Inputs



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

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Calculating the Hazard

Rainfall Intensity

We calculate the hazard for a variety of design storms

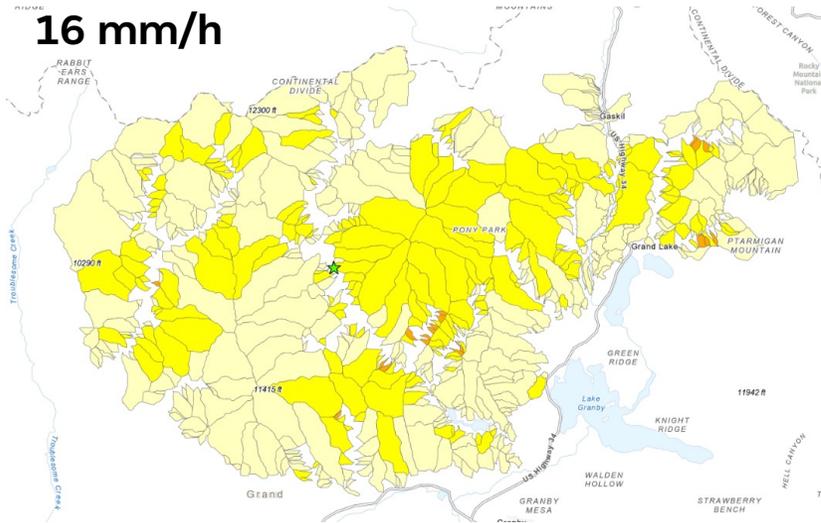
Design Storm: A hypothetical event with a specific rainfall depth and **duration**, or **intensity**

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

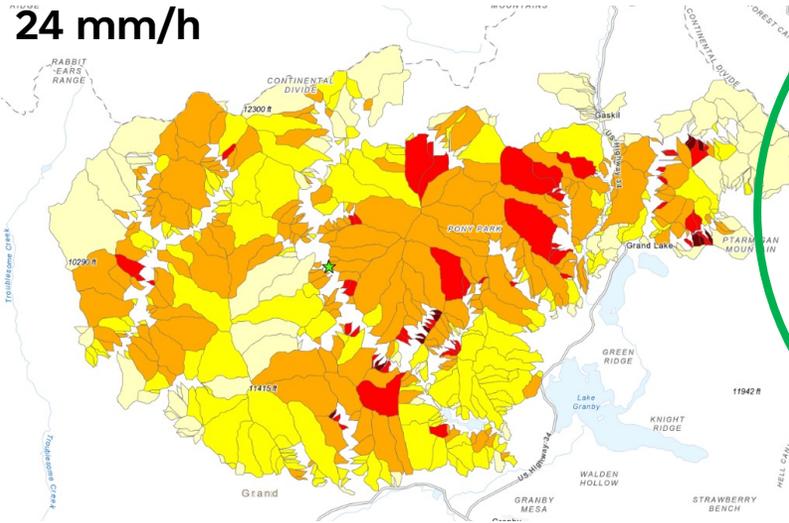
How hard is it raining?

Increased rainfall intensity

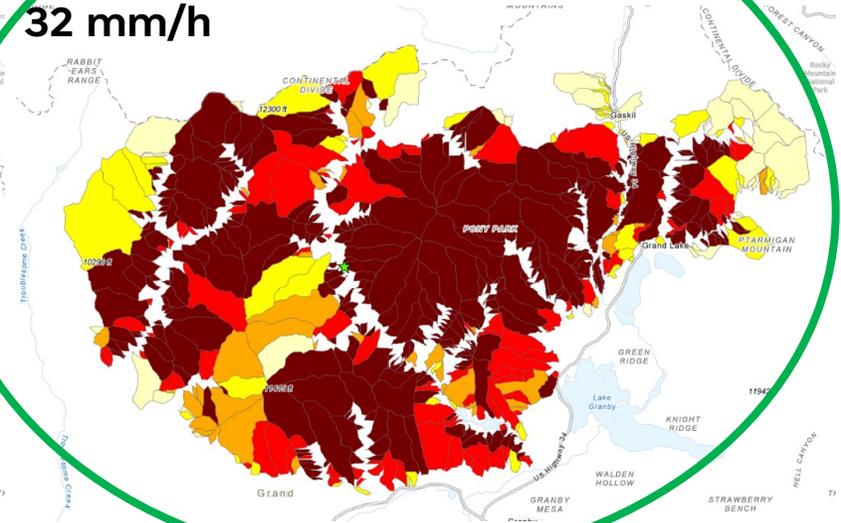
16 mm/h



24 mm/h



32 mm/h

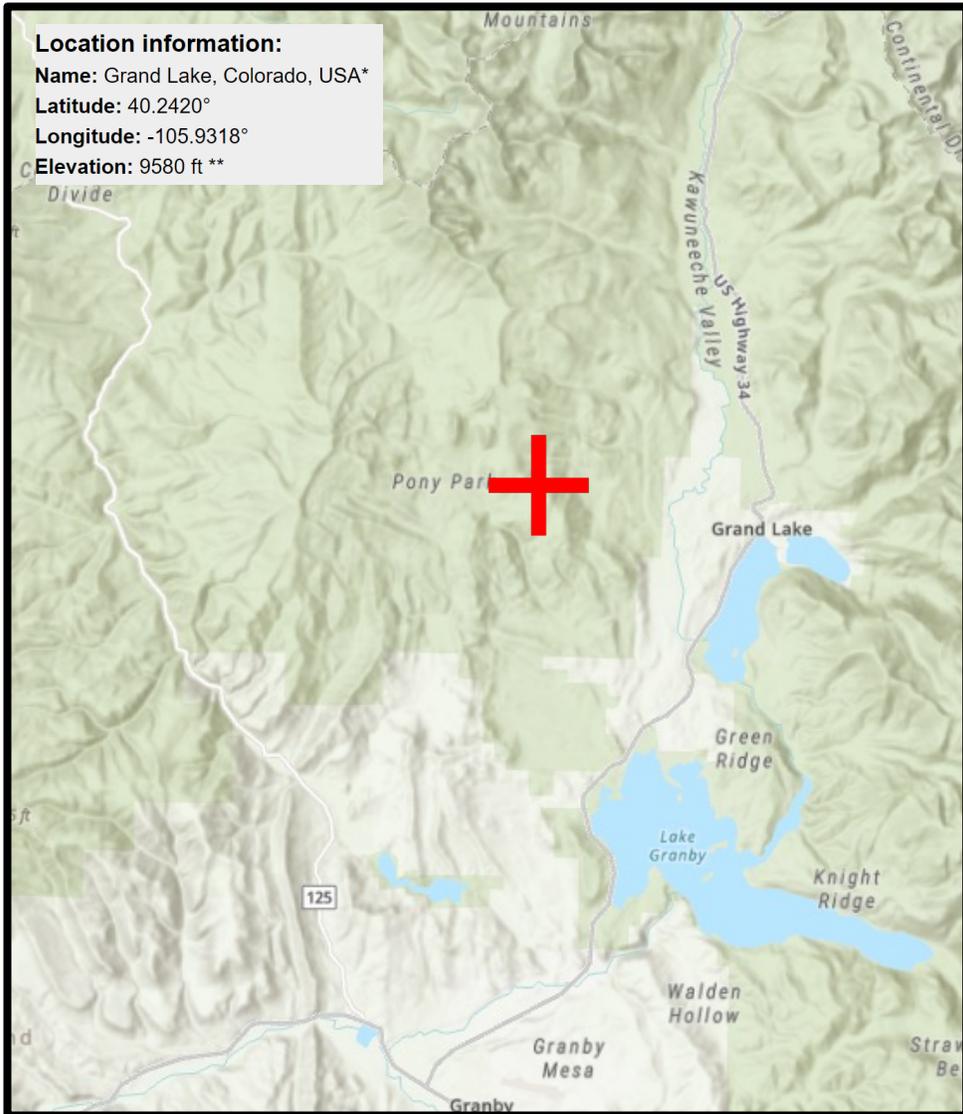


Increased hazard level

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 (31-48)	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

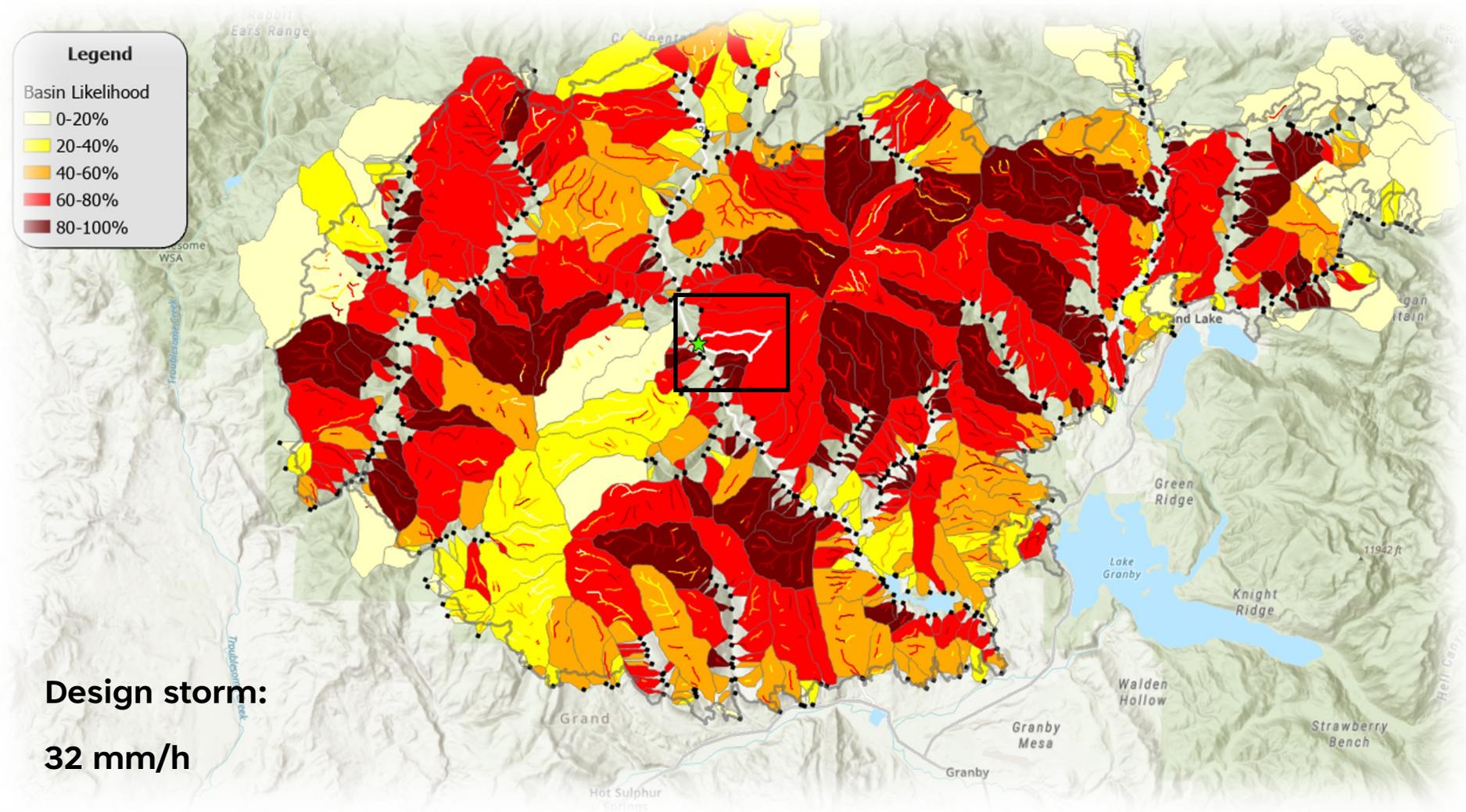
1. Likelihood
2. Volume
3. Combined Hazard

OBJECTID	Shape	Fire_SegmentID	BASIN_ID	Fire_Name	Start_Date	State_Name	Segment_ID	UpArea_km2	BurnArea_km2	StemOrder	Fire_ID	L_X1	L_X2	L_X3	V_X1	V_X2	R	V_X3	X	ExpX	P	PCI	PCI_Legend	LnV	Volume	VolMin	VolMax	VolCI	VolCI_Legend	CombFlz	CombFlzCI	CombFlzCI_Legend	
1	Polygon	ets2020_50	50	East Troublesome	October 14, 2020	Colorado	50	0.1808	0.0105	1	ets2020	0	0.01772	0.289706	11.31923	-13.81551	0	5.656854	-1.912387	0.147227	0.128713	1	0.20%	2.92409	18.617273	2.32566	148.021385	1	+1,000	2	1	Low	
2	Polygon	ets2020_57	57	East Troublesome	October 14, 2020	Colorado	57	0.2162	0.0101	1	ets2020	0	0.01867	0.274719	14.34285	-13.81551	0	5.656854	-1.991503	0.13649	0.120098	1	0.20%	3.317159	27.58189	3.445811	220.778377	2	+1,000	2	1	Low	
3	Polygon	ets2020_65	65	East Troublesome	October 14, 2020	Colorado	65	0.1069	0.0643	1	ets2020	0	0.17537	0.2976939	14.34285	-13.81551	0	5.656854	-1.066019	0.344377	0.256161	2	20.40%	2.450981	11.599725	1.449156	92.849638	1	+1,000	3	1	Low	
4	Polygon	ets2020_77	77	East Troublesome	October 14, 2020	Colorado	77	3.1267	0.0849	1	ets2020	0	0.01208	0.206708	27.51733	-5.20021	0	5.656854	-2.407803	0.090013	0.08258	1	0.20%	6.130702	3397.19499	434.411042	27192.661652	2	1,000 - 10,000	3	1	Low	
5	Polygon	ets2020_84	84	East Troublesome	October 14, 2020	Colorado	84	0.1461	0.0827	1	ets2020	0	0.165382	0.276728	12.03327	-13.81551	0	5.656854	-1.193875	0.303045	0.232567	2	20.40%	3.016914	20.428158	2.552094	163.516556	1	+1,000	3	1	Low	
6	Polygon	ets2020_129	129	East Troublesome	October 14, 2020	Colorado	129	0.8609	0.0263	2	ets2020	0.160881	0.503701	0.18	21.43814	-0.724813	0	5.656854	0.605524	1.832212	0.646919	4	60.80%	8.978199	7828.337851	990.48893	63462.133871	2	1,000 - 10,000	6	2	Moderate	
7	Polygon	ets2020_130	130	East Troublesome	October 14, 2020	Colorado	130	7.1758	2.2119	3	ets2020	0.097295	0.202671	0.18	25.52672	-0.553863	0	5.656854	-1.742828	0.296346	0.228601	2	20.40%	9.944037	20827.657995	2602.003733	166714.340982	3	10,000 - 100,000	5	2	Moderate	
8	Polygon	ets2020_142	142	East Troublesome	October 14, 2020	Colorado	142	0.2455	0.0151	1	ets2020	0	0.039311	0.24	16.7551	-13.81551	0	5.656854	-2.075284	0.125519	0.111521	1	0.20%	3.620752	37.741199	4.715016	302.098257	1	+1,000	2	1	Low	
9	Polygon	ets2020_221	221	East Troublesome	October 14, 2020	Colorado	221	0.7063	0.677	2	ets2020	0.021906	0.219662	0.201661	31.01314	0.654797	0	5.656854	-1.253397	0.285333	0.222113	2	20.40%	10.683608	44073.241439	5506.079405	352782.891048	3	10,000 - 100,000	5	2	Moderate	
10	Polygon	ets2020_222	222	East Troublesome	October 14, 2020	Colorado	222	0.2712	0.2644	2	ets2020	0.038711	0.020963	0.18	15.86667	-0.300224	0	5.656854	0.833335	2.30096	0.69706	4	60.80%	8.38076	4362.322847	544.995919	34918.077626	2	1,000 - 10,000	6	2	Moderate	
11	Polygon	ets2020_242	242	East Troublesome	October 14, 2020	Colorado	242	0.1079	0.0157	1	ets2020	0	0.099383	0.18	10.30908	-5.250997	0	5.656854	-2.089305	0.123773	0.110141	1	0.20%	5.873079	355.341539	44.392894	2844.320304	1	+1,000	2	1	Low	
12	Polygon	ets2020_249	249	East Troublesome	October 14, 2020	Colorado	249	2.3875	1.5166	3	ets2020	0.071613	0.371289	0.18	24.743	0.078187	0	5.656854	-0.371807	0.672282	0.402008	3	40.60%	9.67091	15849.764774	1980.114476	128668.94943	3	10,000 - 100,000	6	2	Moderate	
13	Polygon	ets2020_252	252	East Troublesome	October 14, 2020	Colorado	252	0.5596	0.5596	1	ets2020	0.003524	0.589995	0.18	15.13514	-0.657334	0	5.656854	0.551933	1.736666	0.634584	4	60.80%	6.157102	3488.061922	435.764316	27920.083227	2	1,000 - 10,000	6	2	Moderate	
14	Polygon	ets2020_268	268	East Troublesome	October 14, 2020	Colorado	268	2.2434	0.2274	2	ets2020	0	0.027305	0.23229	23.06656	-13.81551	0	5.656854	-2.108221	0.112723	0.101304	1	0.20%	4.451242	85.733375	10.710689	686.250131	1	+1,000	2	1	Low	
15	Polygon	ets2020_271	271	East Troublesome	October 14, 2020	Colorado	271	0.2825	0.1859	2	ets2020	0	0.170472	0.285566	11.94717	-13.81551	0	5.656854	-1.117101	0.327227	0.246549	2	20.40%	3.005721	20.2	2.523368	166.696528	1	+1,000	3	1	Low	
16	Polygon	ets2020_286	286	East Troublesome	October 14, 2020	Colorado	286	0.137	0.137	1	ets2020	0.009203	0.657813	0.18	12.84224	-1.719431	0	5.656854	0.934064	2.54483	0.717899	4	60.80%	6.0171	14130.673865	2	1,000 - 10,000	6	2	Moderate			
17	Polygon	ets2020_313	313	East Troublesome	October 14, 2020	Colorado	313	0.303	0.303	1	ets2020	0.073229	0.607559	0.18	13.12289	-1.197685	0	5.656854	0.852366	2.347206	0.701252	4	60.80%	5.22105	2210.5	2.1	11684.013743	2	1,000 - 10,000	6	2	Moderate	
18	Polygon	ets2020_315	315	East Troublesome	October 14, 2020	Colorado	315	0.1181	0.0422	1	ets2020	0	0.103559	0.269462	12.95719	-7.80446	0	5.656854	-1.589952	0.208893	0.172787	1	0.20%	5.29	199.1	3.18669	1593.919435	1	+1,000	2	1	Low	
19	Polygon	ets2020_327	327	East Troublesome	October 14, 2020	Colorado	327	0.1	0.0334	1	ets2020	0	0.112527	0.258597	13.74633	-13.81551	0	5.656854	-1.578707	0.2026	0.173067	1	0.20%	3.2396	25.5	3.18669	204.304667	1	+1,000	2	1	Low	
20	Polygon	ets2020_338	338	East Troublesome	October 14, 2020	Colorado	338	0.1015	0.1015	1	ets2020	0	0.493162	0.18	10.03059	-3.091249	0	5.656854	-0.818118	1.02151	0.337	3	30.60%	4.730	47.3	93.43824	5986.730325	1	+1,000	4	2	Moderate	
21	Polygon	ets2020_343	343	East Troublesome	October 14, 2020	Colorado	343	1.3032	0.0533	1	ets2020	0	0.010246	0.184154	20.93679	-13.81551	0	5.656854	-0.219	0.078566	0.43	1	0.20%	6.095139	8911.864895	1113.361172	71334.745519	2	1,000 - 10,000	6	2	Moderate	
22	Polygon	ets2020_354	354	East Troublesome	October 14, 2020	Colorado	354	0.682	0.6668	1	ets2020	0	0.063632	0.18	22.0017	-6.65	0.65	0	5.656854	-1.747904	0.19	0.19	0.20%	7.195472	64.999011	6.12034	520.28256	1	+1,000	2	1	Low	
23	Polygon	ets2020_380	380	East Troublesome	October 14, 2020	Colorado	380	0.5601	0.0448	2	ets2020	0.009926	0.06055	0.24	25.18591	-0.504	0	5.656854	-1.413709	0.24	0.24	0.20%	9.095139	8911.864895	1113.361172	71334.745519	2	1,000 - 10,000	6	2	Moderate		
24	Polygon	ets2020_393	393	East Troublesome	October 14, 2020	Colorado	393	0.2881	0.0102	1	ets2020	0	0.33317	0.18	13.81551	-0.68	0.18	0	5.656854	-1.5189	0.199133	0.096395	1	0.20%	3.730783	41.711774	5.211061	333.880601	1	+1,000	2	1	Low
25	Polygon	ets2020_402	402	East Troublesome	October 14, 2020	Colorado	402	0.1267	0.0405	1	ets2020	0	0.1262018	11.1	-4.45675	0.18	13.81551	0	5.656854	-2.451	0.232996	0.198625	1	0.20%	6.329183	560.699071	70.045129	4488.096278	1	+1,000	2	1	Low
26	Polygon	ets2020_404	404	East Troublesome	October 14, 2020	Colorado	404	0.1034	0.0539	1	ets2020	0	0.1	0.233947	11.61	-1.17	0	5.656854	-1.17998	0.309747	0.236494	2	20.40%	5.63892	281.158907	35.125242	2250.527733	1	+1,000	3	1	Low	
27	Polygon	ets2020_430	430	East Troublesome	October 14, 2020	Colorado	430	2.2324	1.3176	1	ets2020	0	0.18	19.91101	-0.441993	0	5.656854	-0.926915	0.395773	0.283551	2	20.40%	8.855487	7012.765872	876.106328	56133.466423	2	1,000 - 10,000	4	2	Moderate		
28	Polygon	ets2020_462	462	East Troublesome	October 14, 2020	Colorado	462	0.1422	0.0102	1	ets2020	0	0.01	0.262275	11.60585	-13.81551	0	5.656854	-1.928974	0.145734	0.121797	1	0.20%	2.961349	19.324031	2.416155	154.676004	1	+1,000	2	1	Low	
29	Polygon	ets2020_479	479	East Troublesome	October 14, 2020	Colorado	479	0.46	0.4641	1	ets2020	0	0.677354	0.18	13.58652	-0.918392	0	5.656854	1.002878	2.728161	0.731624	4	60.80%	7.8610	2596.190378	334.324651	20781.125178	2	1,000 - 10,000	6	2	Moderate	
30	Polygon	ets2020_492	492	East Troublesome	October 14, 2020	Colorado	492	0.0191	0.0191	1	ets2020	0	0.078116	0.237118	12.26432	-6.259783	0	5.656854	-1.883438	0.152066	0.131995	1	0.20%	5.76702	319.58394	39.925689	2586.099715	1	+1,000	2	1	Low	
31	Polygon	ets2020_508	508	East Troublesome	October 14, 2020	Colorado	508	4.2	0.3395	1	ets2020	0.019729	0.041725	0.24	27.355	-1.62794	0	5.656854	-1.99764	0.135655	0.119451	1	0.20%	9.396264	12043.304975	1504.572646	96040.260295	3	10,000 - 100,000	4	2	Moderate	
32	Polygon	ets2020_511	511	East Troublesome	October 14, 2020	Colorado	511	0.285	0.285	1	ets2020	0.016878	0.048265	0.24	25.51534	-1.874615	0	5.656854	-1.971939	0.139187	0.122181	1	0.20%	9.066073	8673.888802	1083.630768	69429.873281	2	1,000 - 10,000	3	1	Low	
33	Polygon	ets2020_542	542	East Troublesome	October 14, 2020	Colorado	542	0.283	0.0077	1	ets2020	0.000707	0.023699	0.24	23.04954	-5.278515	0	5.656854	-2.155205	0.115879	0.103846	1	0.20%	7.522348	1848.903335	230.963886	14799.489273	2	1,000 - 10,000	3	1	Low	
34	Polygon	ets2020_699	699	East Troublesome	October 14, 2020	Colorado	699	0.8733	0.8733	1	ets2020	0	0.112973	0.281911	11.7668	-11.75167	0	5.656854	-1.445764	0.235566	0.190654	1	0.20%	3.725257	41.481892	5.182343	332.040596	1	+1,000	2	1	Low	
35	Polygon	ets2020_701	701	East Troublesome	October 14, 2020	Colorado	701	4.1662	3.4448	3	ets2020	0.051594	0.555594	0.20565	31.3939	1.885544	0	5.656854	0.688854	1.951999	0.661246	4	60.80%	10.896176	54077.612567	6755.927613	432862.568752	3					

USGS Hazard Assessments Results

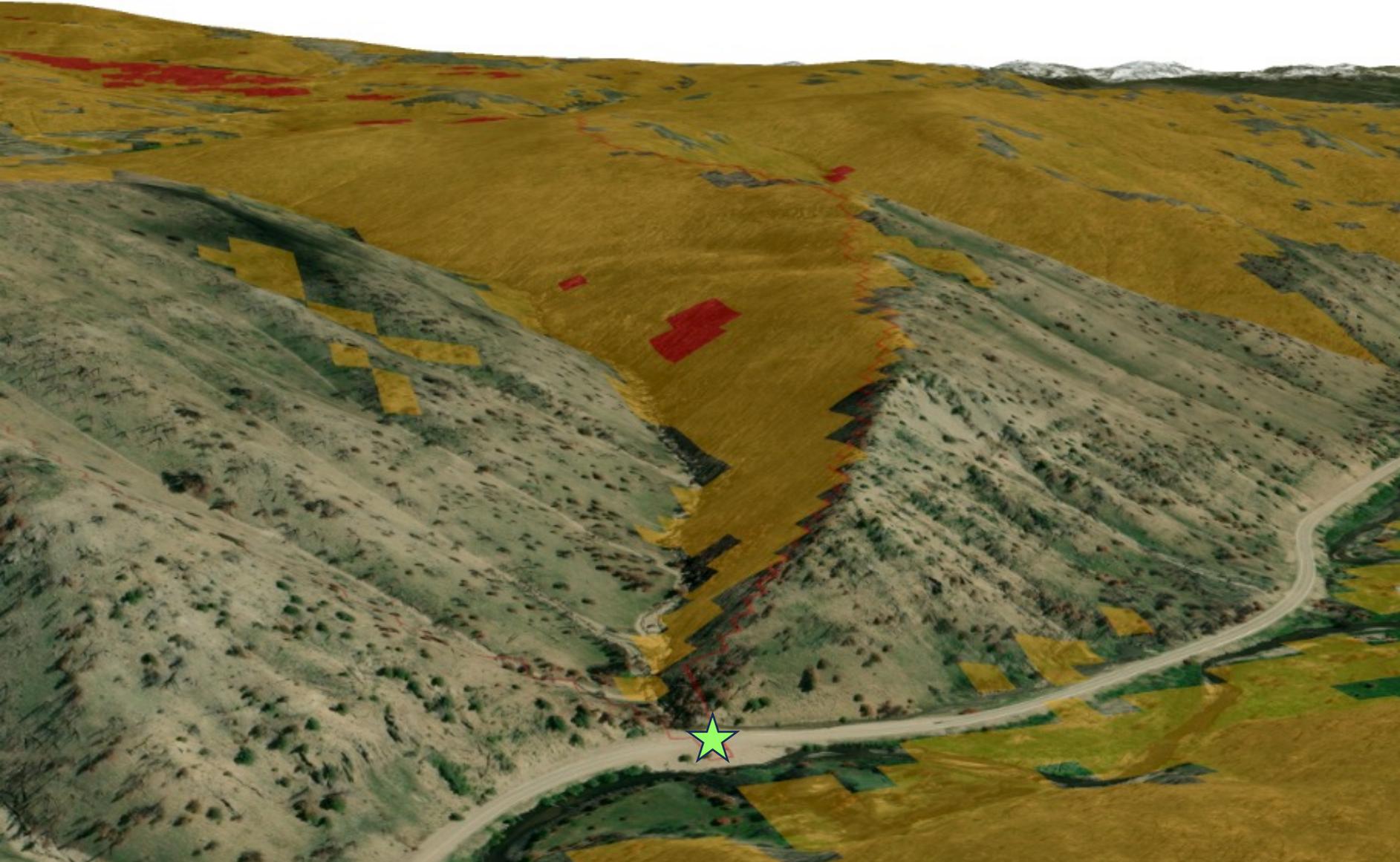
Hazard Maps

1. Likelihood
2. Volume
3. Combined Hazard



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

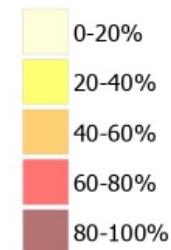
Basin-scale

Which design storm?

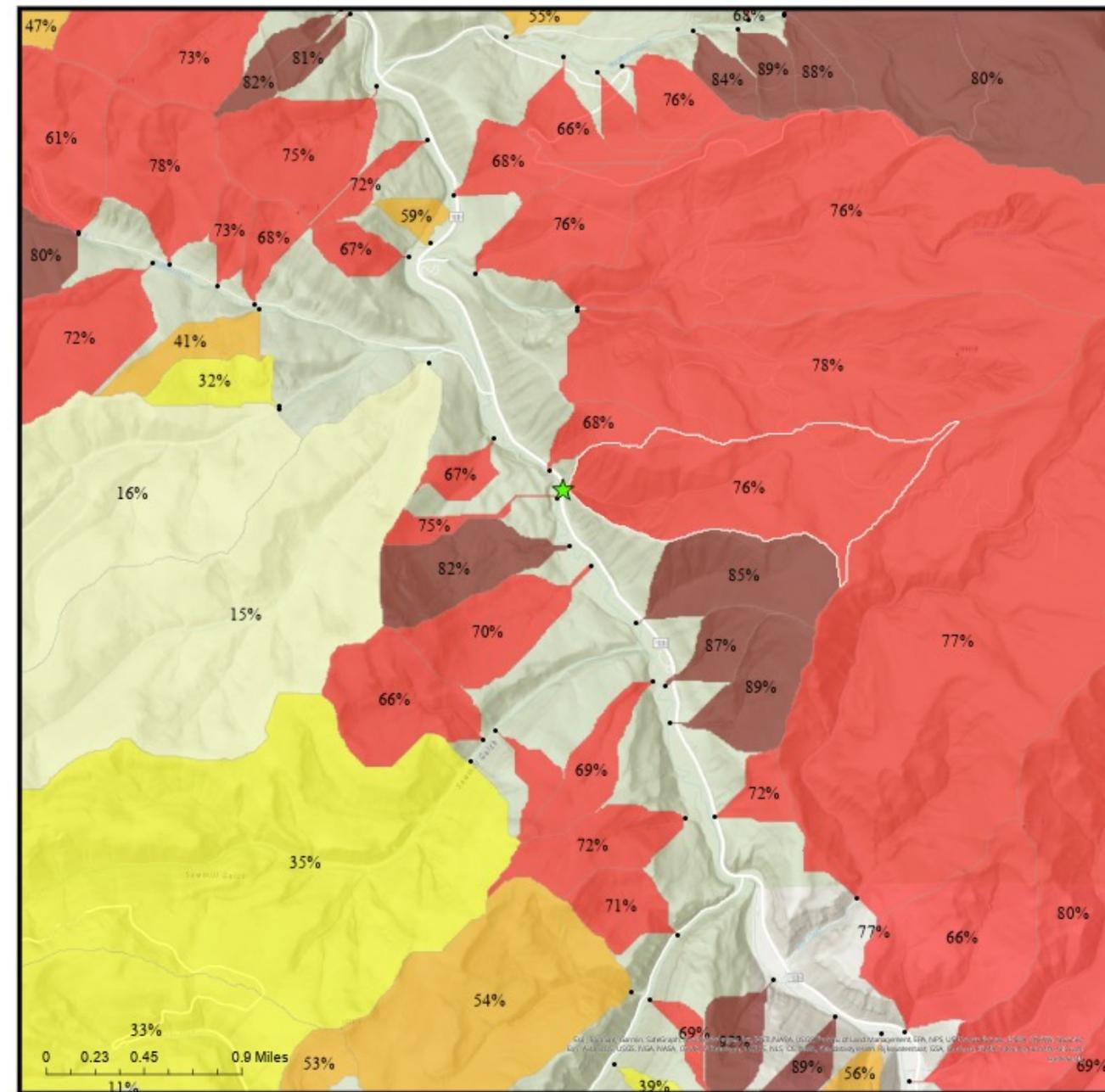
32 mm/h

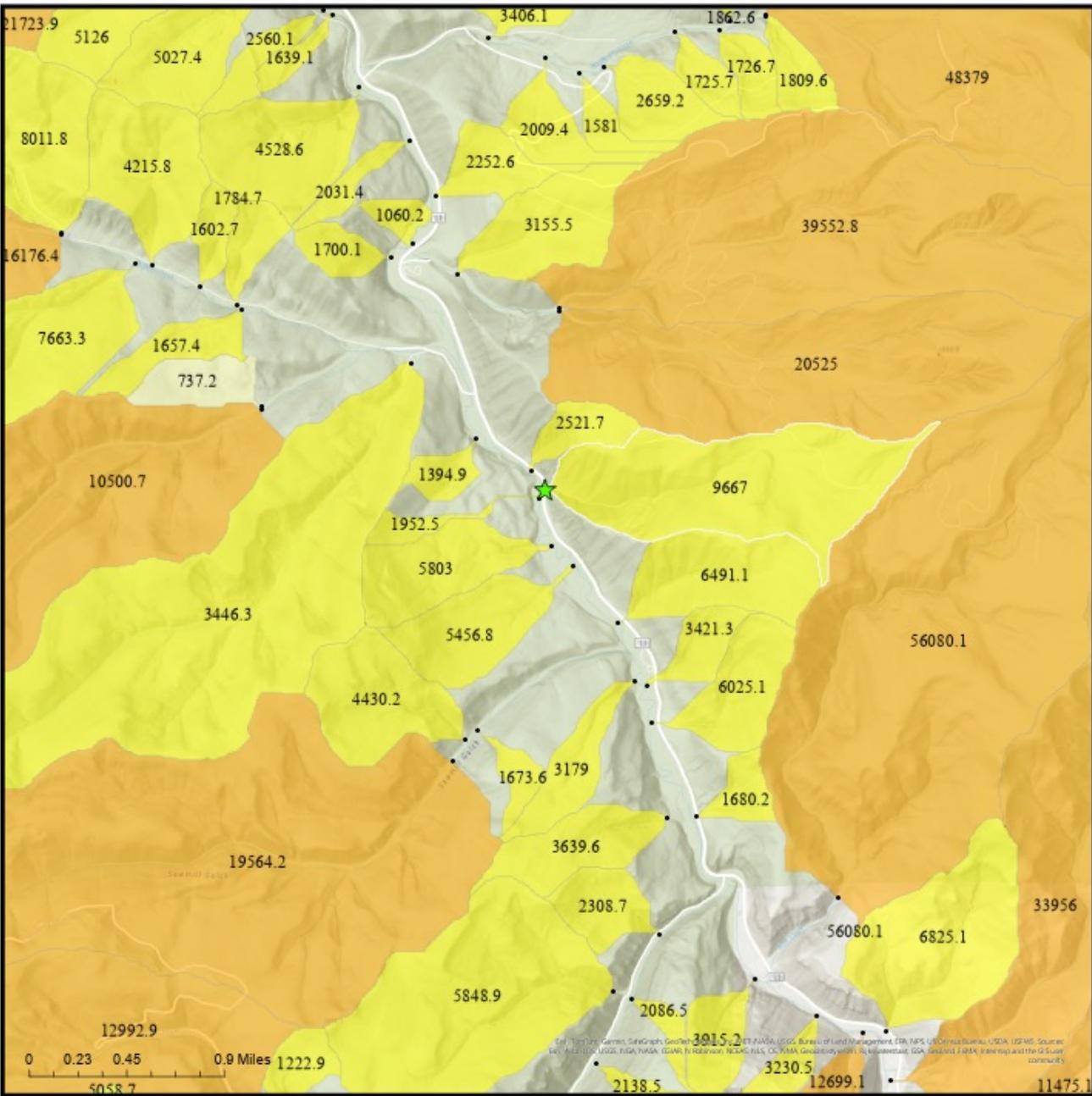
Debris-flow Likelihood

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



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





Volume

Basin-scale

Which design storm?

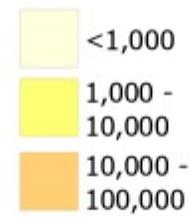
32 mm/h

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

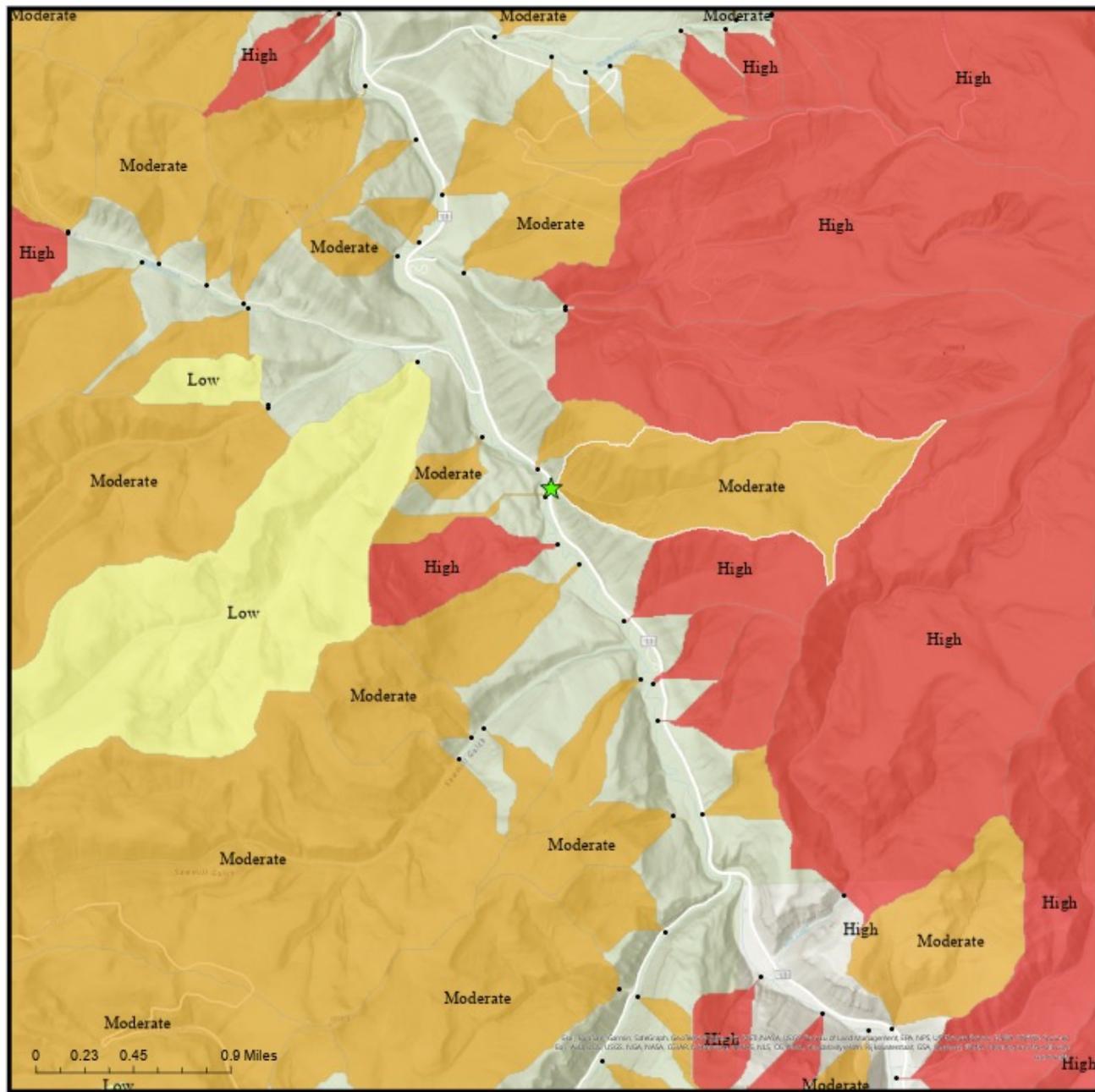
Debris-flow Volume

Volume	9667
VolMin	1207
VolMax	77,379
VolCI	2
VolCI_Legend	1,000-10,000

Volume (m³)



Volume Range
1,207-77,379 m³



Combined Hazard

Basin-scale

Which design storm?

32 mm/h

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

	<u>< 1,000</u>	<u>1,000 - 10,000</u>	<u>10,000 - 100,000</u>	<u>> 100,000</u>
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



Rainfall Thresholds

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

Support Early Warning

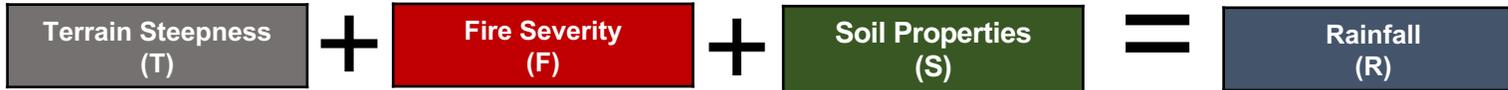
* At 347 PM MDT, Doppler radar indicated thunderstorms producing heavy rain over the Grizzly Creek Burn Area. Between 0.1 and 0.3 inches of rain have fallen. The expected rainfall rate is 0.5 to 1 inch in 1 hour. Additional rainfall amounts of 0.1 to 0.3 inches are possible in the warned area. Flash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



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



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



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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.

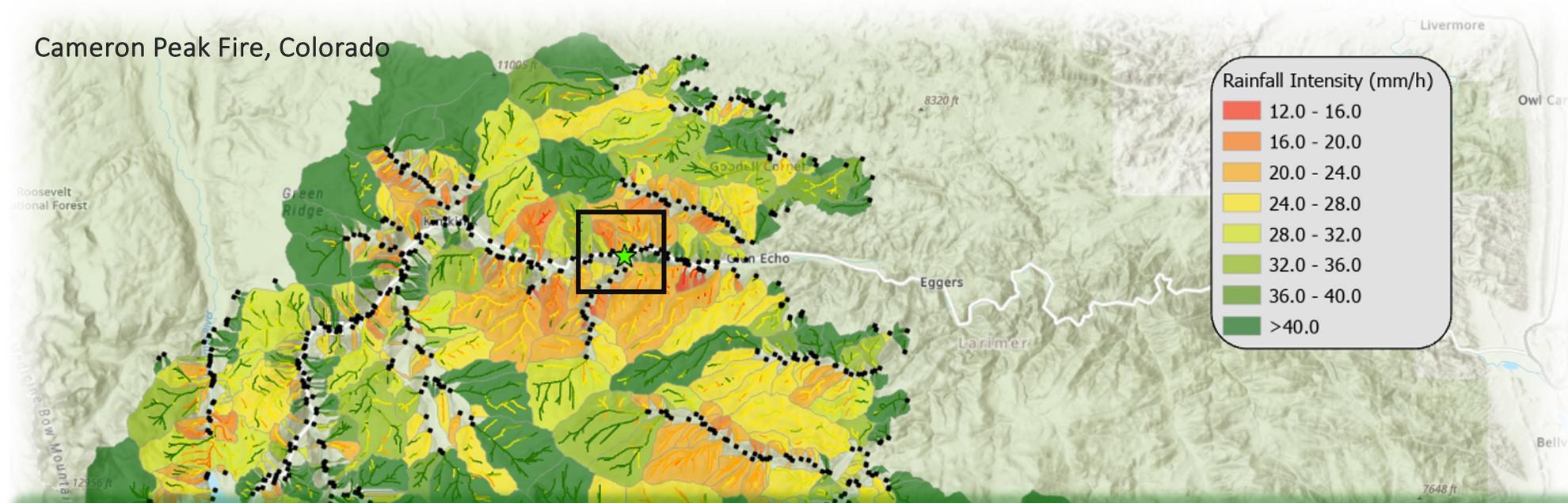
* Corresponding author at: Box 25046 MS966 DFC, Denver, CO 80225, USA.
E-mail address: dstaley@usgs.gov (D.M. Staley).

Rainfall Thresholds

Year 1 Firewide rainfall thresholds

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

Cameron Peak Fire, Colorado



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 10,000m³, 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

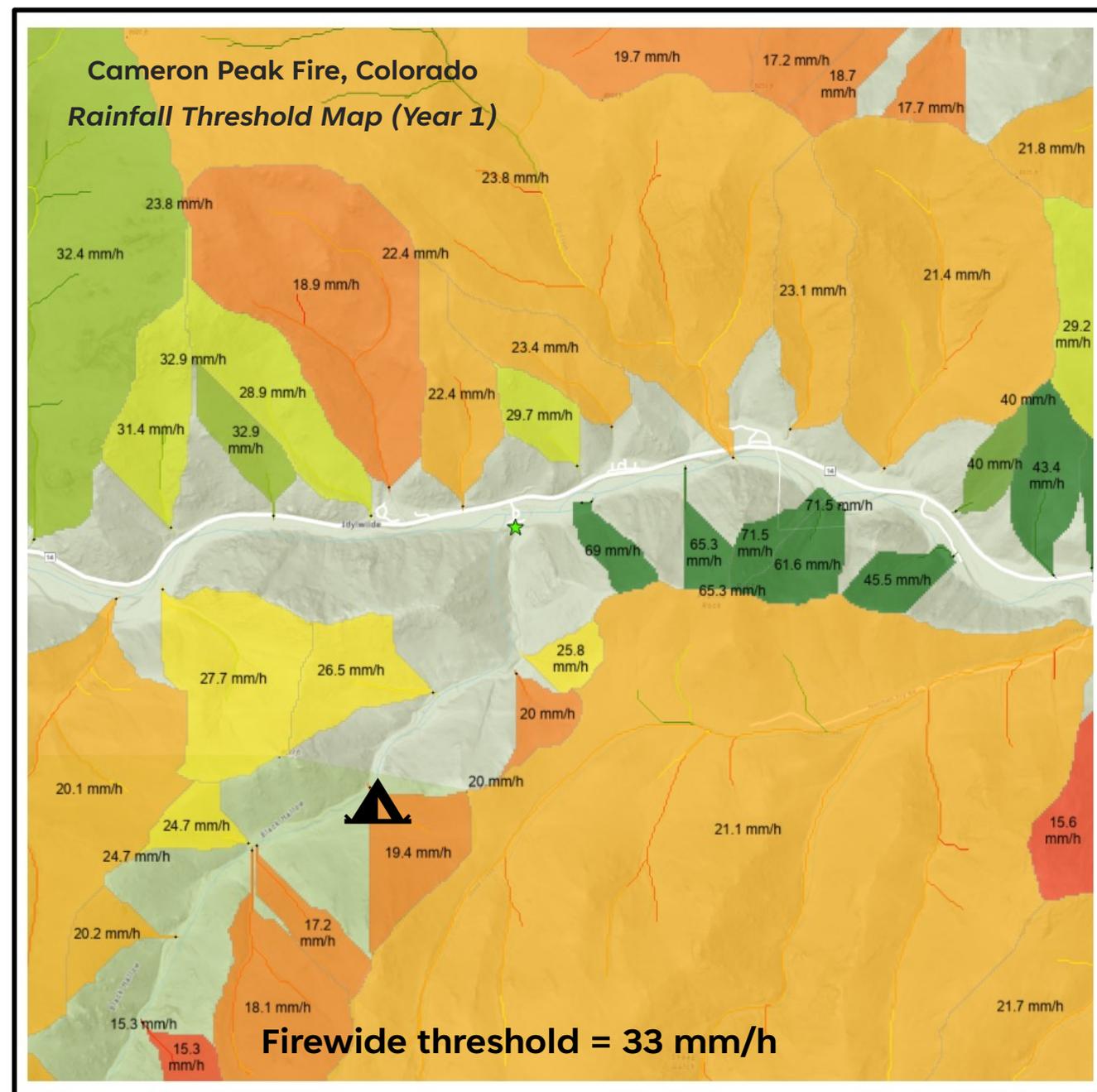
Year 1: Site-specific Thresholds

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



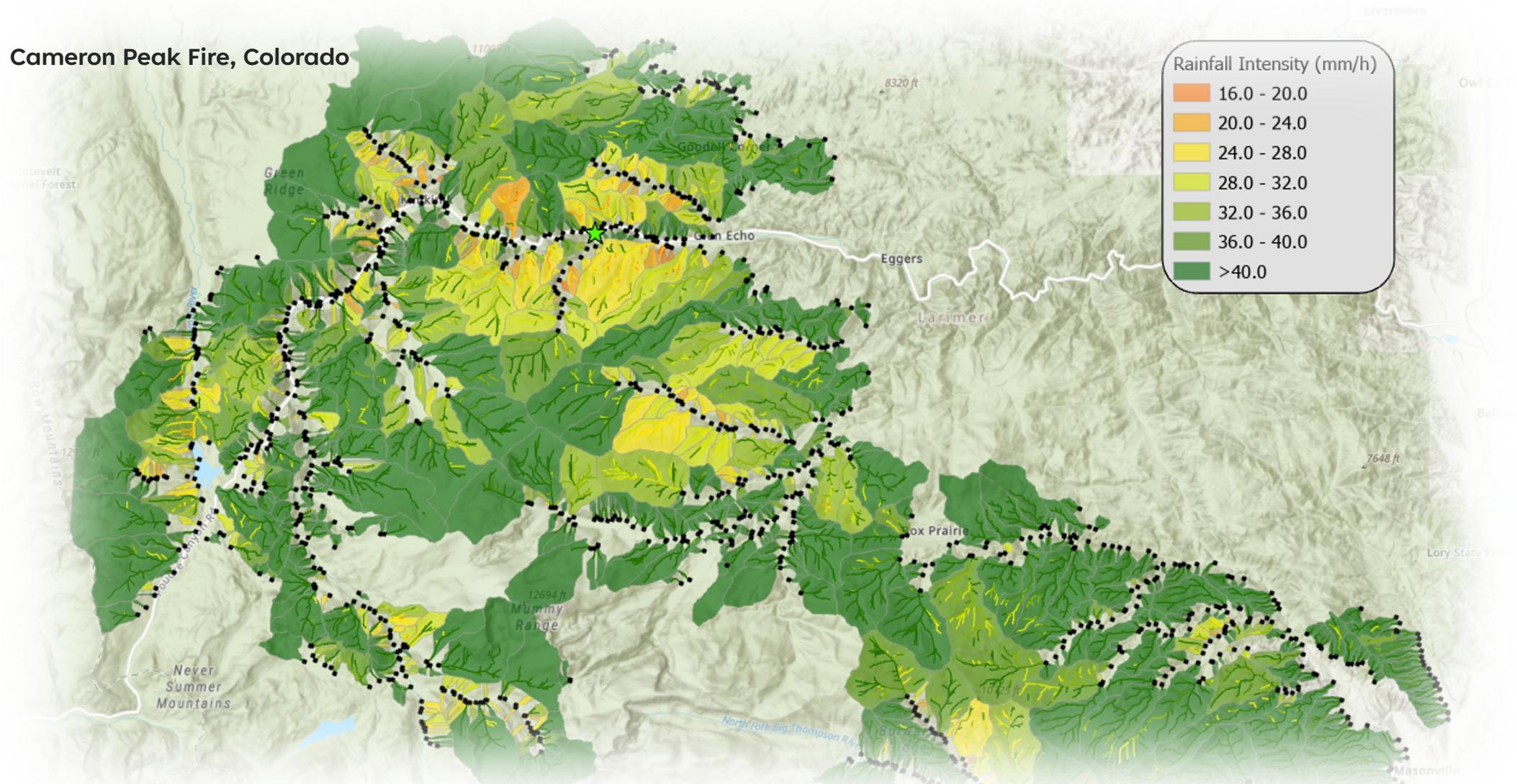


Rainfall Thresholds

Year 2: Firewide Thresholds

Thresholds change over time as the burn area recovers

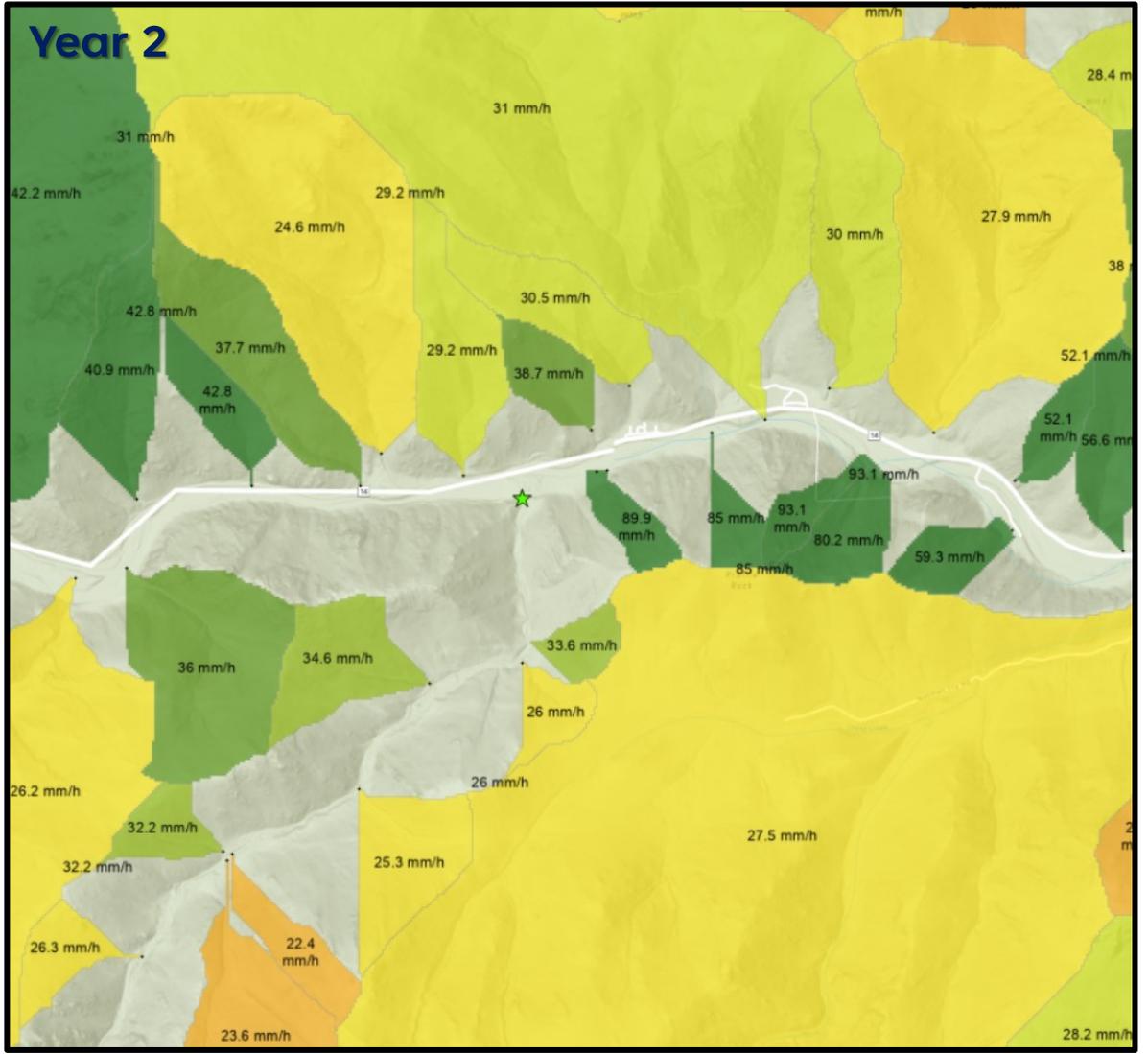
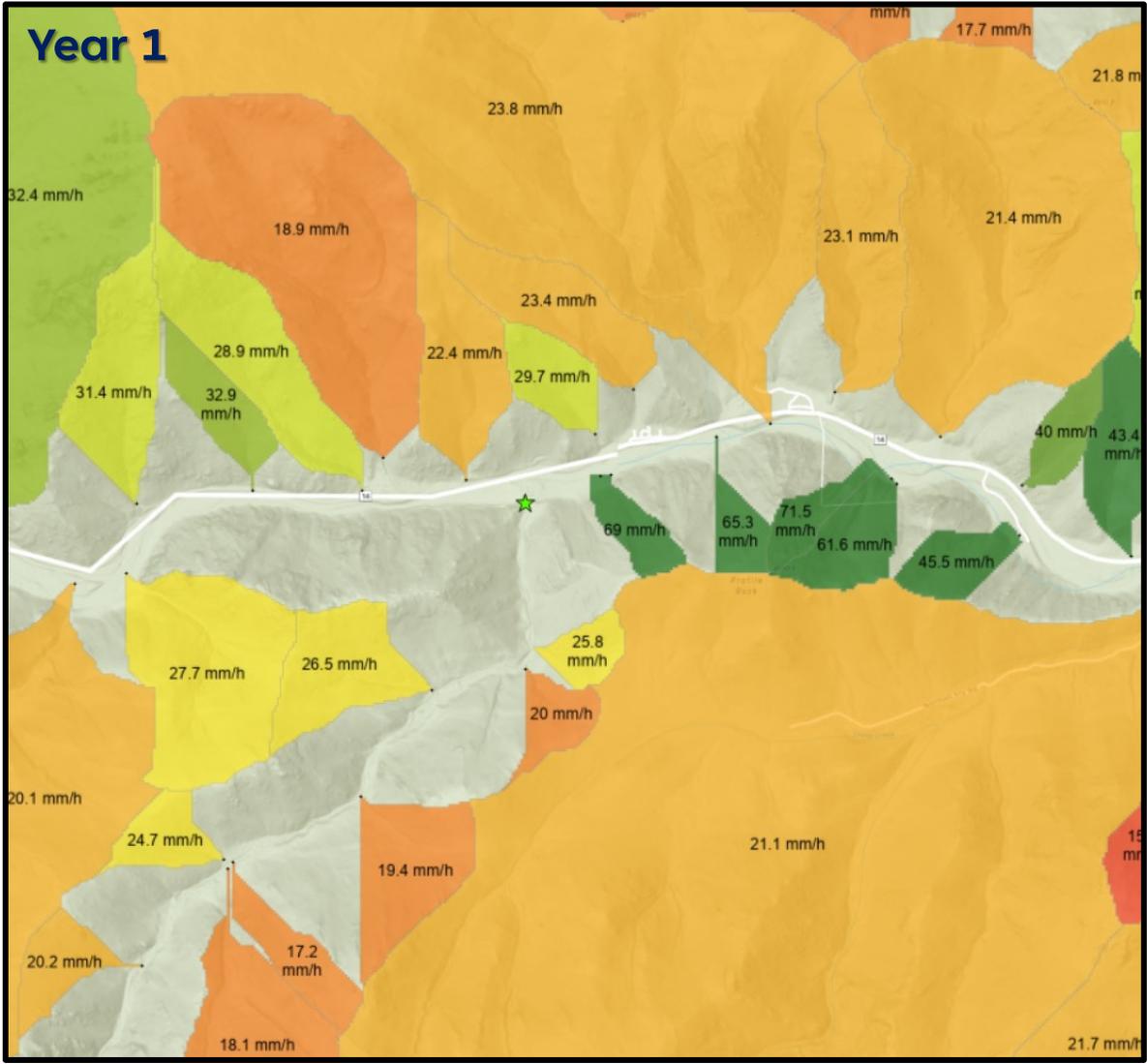
Cameron Peak Fire, Colorado



Rainfall Thresholds

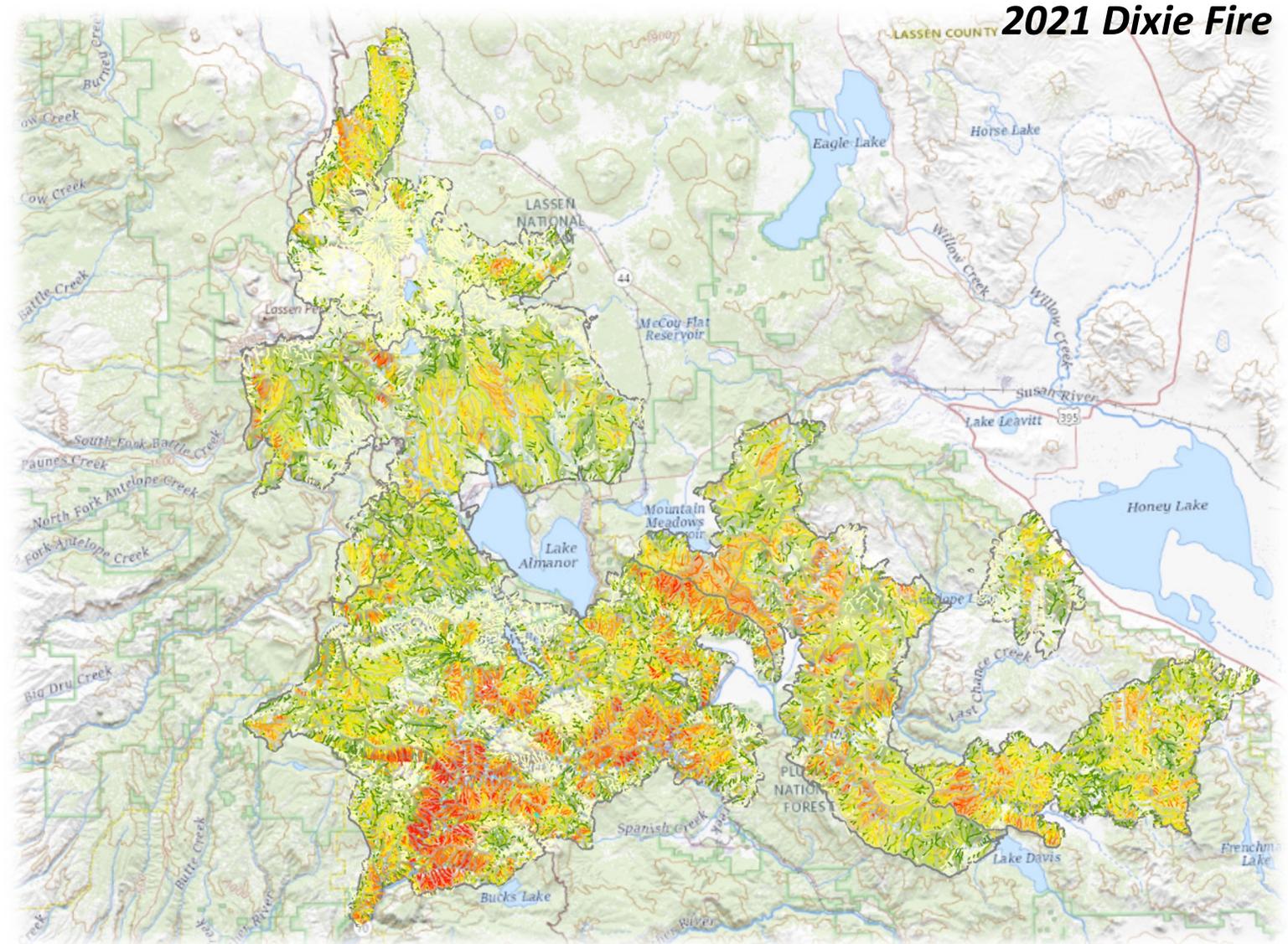
Cameron Peak burn area

Site-specific



Can you think of challenges with using rainfall thresholds?

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



Model Limitations

Accessing the Data

How do I access the data?

Data download

USGS Post Wildfire Debris Flow Hazard Assessment Viewer

Select Fire Year
View All Fire Years

Select by Fire
East Troublesome

State Filter
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/dashboard/c09fa874362e48a9afe79432f2efe6fe#fire=East Troublesome

References



Hazard Assessment Code

King, J., 2023, pdf - 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

Staley, D. M., Negri, J. A., Kean, J. W., Laber, J. L., Tillery, A. C., & Youberg, A. M. (2016). *Updated logistic regression equations for the calculation of post-fire debris-flow likelihood in the western United States* (No. 2016-1106). US Geological Survey.

Gartner, J. E., Cannon, S. H., & Santi, P. M. (2014). Empirical models for predicting volumes of sediment deposited by debris flows and sediment-laden floods in the transverse ranges of southern California. *Engineering Geology*, 176, 45-56.

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

Graber, Andrew P., Matthew A. Thomas, and Jason W. Kean. "How Long Do Runoff-Generated Debris-Flow Hazards Persist After Wildfire?." *Geophysical Research Letters* 50.19 (2023): e2023GL105101.

Thank you!

jkostelnik@usgs.gov

Questions? Feedback?