WALLOW FIRE

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Post-Burn Increased Flash Flood Risk Analysis

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USFS aerial image of burned watershed, Wallow Fire Burn Area, with community directly downstream.

Abstract.

In the desert southwest of the United States, wildfire alters the hydrologic response of watersheds greatly increasing the magnitudes and frequency of flash floods. The NOAA National Weather Service is tasked with the issuance of flash flood warnings to save life and property. Basins impacted by the Wallow Fire are expected to see 5-year peak flows that range from 832 to 18,080 cfs. The post-burn 5-year peak flows are 1.0 to 89.1 times greater than pre-burn flows. The storm duration for the NWS post-burn peak flows is equal to the time of concentration for each basin evaluated. For the 53 basins studied, the time of concentration ranged from 13 to 295 minutes. Of the 12 Wallow Wildfire Forest Service BAER Team Wildcat-5 basins evaluated, 11 were determined susceptible to hyper-concentrated flows at their outlet. Of the 27 Wallow Wildfire Forest Service BAER Team HEC-RAS basins evaluated, 10 were determined to be susceptible to hyper-concentrated flows at their outlet. Of the 14 Apache County identified basins evaluated, 12 were determined to be susceptible to hyper-concentrated flows at their outlet. For the 33 basins susceptible to hyper-concentrated flows at their outlet the storm duration ranges from 13 to 171 minutes.

INTRODUCTION

This report is an assessment of the impact on the future hydrologic response of basins burned by the 2011 Wallow Fire in Apache, Navajo, Graham, and Greenlee, Counties, Arizona; and Catron County, New Mexico. These impacts are possible during the next few years, prior to the hydrologic recovery of the watersheds. Empirical equations developed by NWS using post-burn data from fires that have occurred in the mountainous terrain of Southeast Arizona are used to estimate the 2-year, 5-year, and 10-year post-burn peak flows and the associated increased flash flood risk. The basins selected for analysis (Figure 1) include 39 basins selected from those defined by the Wallow Wildfire Forest Service BAER Team, and an additional 14 sites selected from data provided by Apache County and the Arizona Water Science Center, United States Geological Survey (USGS).

This report provides an estimate of potential flows after a burn with an emphasis on the first significant flash flood that could "likely" occur in each of the studied basin. It is the experience of the authors that these "first flush" peak flows are often hyper-concentrated flows. Thus the peaks from each basin are essentially sediment carrying water flows with entrained post-burn debris. The 5-year return interval is used for this study because the calculated peaks then have a 67% chance of being equaled or exceeded one or more times during an assumed burn recovery period of five years. The 2-year and 10-year post-burn peak flows are also presented to help better define flash flood risk. By convention, the storm duration for these events is equal to or greater than the time of concentration of the basins. These are not debris flows and the equations are not suitable for forecasting post wildfire debris flow hazards.

Flash floods pose a significant threat to life and property in and downstream of burned areas. This report does not seek to determine if a given structure is at risk of damage or destruction. Such a determination is beyond the scope of this report or the expertise of the authors. Any statements about increases in post-burn flash flood risks are general in nature and based on a comparison of pre- and post-burn peak flows.

METHODOLOGY

In studies of post-burn peak flows throughout southeast Arizona, Reed and Schaffner (2007 and 2008) have demonstrated that peak flows can be estimated for burned basins using a multivariate runoff index defined by several watershed characteristics. Therefore, a series of empirical equations were developed by Reed to estimate peaks flows with 2-year through 10-year recurrence intervals from both small and larger sized burned basins. The basin properties used are 1) the hyper-effective drainage area, the area of the basin with moderate and high severity burn, in square miles, 2) the modified channel relief ratio, and 3) the mean basin elevation, in thousands of feet above mean sea level. Figure 2 shows the areal extent of moderate and high burn severity within the Wallow Fire.

For the Wallow Fire, an analysis of 53 watersheds using the Reed-Schaffner Equation 3 was performed. Equation 3 is a best-fit curve that uses a multivariate runoff index. For the purpose of this study the channel relief ratio was used unmodified. The channel relief ratio therefore was calculated by subtracting the elevation of the basin outlet in feet from the maximum basin elevation in feet and then dividing this difference by the channel stream length in feet. The channel stream length was measured from the maximum basin elevation to the basin outlet. This was done because the Wallow Fire occurred outside of the area for which the original equations were developed by Reed. This approach, using the channel relief ratio unmodified, has also recently been used for several basins burned by the 2011 Horseshoe 2 Fire. The post-burn flows were calculated for the 2-year, 5-year, and 10-year storms with duration equal to or greater than the watershed's time of concentration (ranged from 13 to 295 minutes). The data used in these calculations were provided by the U.S. Forest Service and the U.S. Geological Survey.

The Reed-Schaffner equations apply where: 1) the storm duration is greater or equal to the basin's time of concentration, 2) the event is the first major flush after the fire, 3) water repellent soils are assumed present, and 4) the core of the storm moves over at least a portion of the hyper-effective drainage area. The Reed-Schaffner equations were not used for watersheds with: 1) drainage area less than 1 square mile, 2) drainage area greater than 50 square miles, 3) elevation change less than 1000 feet, 4) no hyper-effective hydrologic soil group D, and/or 5) no hyper-effective hydrologic soil group C unless hydrologic soil group D coverage was significant. The hydrologic soil groups were evaluated only for those basins where these data were available.

Since equation 3 only calculates runoff from the hyper-effective drainage area, the pre-burn 2-year, 5-year, or 10-year runoff from the remaining portion of the basin was added to the results of equation 3. The pre-burn 2-year, 5-year, and 10-year runoffs were calculated using the USGS equations for region 11 or 14, Thomas (1997). For the basins identified by Apache County, the pre-burn values previously calculated by the USGS were used. Final results reflect the 2-year, 5-year, and 10-year post-burn runoffs from the entire basin.

The calculated flash flood generated peak flows from each basin are essentially sediment carrying water flows with entrained post-burn debris, often referred to as hyper-concentrated flows. In order to provide an estimated of percent water for calculated peaks, the multivariate runoff index (mvi) was ranked (Figure 15). The first 3 basins with mvi values greater than 7.00 were assigned 40%, the next 10 basins with mvi values greater than 2.5 were assigned 60%, the next 20 sites with mvi values greater than 0.75 were assigned 80%, the next 8 basins with values greater than 0.50 were assigned 90%, and the remaining 12 basins

were assigned 100%. Therefore, of the 53 basins ranked, 33 were determined to be susceptible to hyper-concentrated flows at their outlet. However, hyper-concentrated flows may occur elsewhere within the burn especially right below hyper-effective drainage areas if the local drainage is steep. As previously stated, hyper-concentrated flows are not debris flows and the equations are not suitable for forecasting post wildfire debris flow hazard.

Selected basin data are presented in Figures 2-5. Study results including the calculated post-burn peak flows are presented in Figures 6-14. Estimates of percent water for the calculated hyper-concentrated flows are presented in Figure 15. As stated previously, a hydrologic recovery period of five years was assumed. The projected flows are for first flush flows from a basin. Once an event has occurred within a basin, subsequent flows for the same rainfall will most likely be reduced as the sediment concentration of the flows decreases. Relative increase in flash flood risk is provided in Figures 6-14, and 16-24.

FINDINGS

PEAK FLOWS: The 53 basins selected for analyses (Figure 1) are a subset of those defined by the Wallow Wildfire Forest Service BAER Team plus additional basins requested by Apache County. These basins impacted by the Wallow Fire are expected to see 2-year post-burn peak flows that range from 255 to 8,833 cfs (Figures 6-8). The post-burn 2-year peak flows are 1.1 to 208 times greater than pre-burn peak flows. These basins are expected to see 5-year post-burn peak flows that range from 832 to 18,080 cfs (Figures 9-11). The post-burn 5-year peak flows are 1.0 to 89.1 times greater than pre-burn peak flows. These basins are expected to see 10-year post-burn peak flows that range from 1,562 to 30,936 cfs (Figures 12-14). The post-burn 10-year peak flows are 1.0 to 128 times greater than pre-burn peak flows. The 10-year post-burn peak flow for Drainage Area 19, 30,963 cfs, is greater than 18,000 cfs, the potential maximum peak floodflow estimated for the basin using the envelope curve for region 16 developed by Crippen and Bue (1977). However, 40% of the peak flow (the estimated percent water of the peak flow) is 12,385 cfs. The basin's slope is uncharacteristically steep when compared to the slopes of the other evaluated basins in the burned area. The storm duration for the NWS post-burn peak flows is equal to the time of concentration for each basin evaluated. For the 53 basins studied, the time of concentration ranged from 13 to 295 minutes.

ESTIMATED PERCENT WATER FOR HYPER-CONCENTRATED FLOWS: As previously stated the calculated peaks from each basin are essentially sediment carrying water flows with entrained post-burn debris. The estimated percent water for the flows from the 53 selected basins is expected to range from 40 to 100 percent (Figure 15). Of the 53 basins studied, 33 basins are susceptible to hyper-concentrated flows at their outlet (i.e., have estimated percent water of 40, 60, or 80 percent).

RELATIVE INCREASED FLASH FLOOD RISK: To evaluate the relative increase in flash flood risk, the 53 basins were ranked by post-burn yield and assigned a relative increased flash flood risk. Basins with yields greater than 2000 cfs per square mile were assigned extreme, basins between 2000 and 1000 cfs per square mile were assigned high, basins between 1000 and 100 cfs per square mile were assigned moderate, and basins below 100 cfs per square mile were assigned low. This was done for the 2-year, 5-year, and 10-year events as is shown on Figures 6-14. This relative increase in flash flood risk is shown spatially in Figures 16-24.

CONCLUSIONS

Storms with time of concentrations from 13 to 171 minutes over the burn area will cause significant increases in peak flows from many of the impacted basins during the recovery period. The shorter duration storms will impact the headwater basins, and the larger duration storms will impact all 33 basins determined to be susceptible to hyper-concentrated flows at their outlet. The relative increased flash flood risk for 53 basins has been identified and is shown on Figures 6-14. To help better define the risk, the risk is shown for 2-year, 5-year, and 10-year events. Eight basins of particular interests are:

- **Drainage Area 19**
- **Slade Reservoir 2**
- **Eager Wash A**
- **Drainage Area 22**
- **Butler Canyon**
- **Watts Creek**
- **Eagar A – Wash**
- **Nutrioso – Watts Creek**

The first seven basins were selected because they have time of concentrations equal to or less than 30 minutes and potentially high impacts with elevated post-burn flows. The eighth basin, Nutrioso – Watts Creek, was added because it was the remaining basin with an extreme 5-year relative increased flash flood risk. All eight of these basins may experience potentially high impacts with elevated post-burn flows provided the core of the storm passes over the hyper-effective burn area and the duration of the storm is equal to or greater than the basin's time of concentration. For these eight basins post-burn flow results are:

- **Drainage Area 19** (Storm Duration: 13 Minutes)
  5-Year Post-Burn Flow (Eq. 3): 18,080 cfs
  Estimated % Water: 40%
  2-Year Relative Increased Flash Flood Risk: Extreme
  5-Year Relative Increased Flash Flood Risk: Extreme
  10-Year Relative Increased Flash Flood Risk: Extreme
  2-Year precipitation: 0.59 inches
  5-Year precipitation: 0.78 inches
  10-Year Precipitation: 0.92 inches

- **Slade Reservoir 2** (Storm Duration: 17 Minutes)
  5-Year Post-Burn Flow (Eq. 3): 2,782 cfs
  Estimated % Water: 80%
  2-Year Relative Increased Flash Flood Risk: High
  5-Year Relative Increased Flash Flood Risk: Extreme
  10-Year Relative Increased Flash Flood Risk: Extreme
  2-Year precipitation: 0.66 inches
  5-Year precipitation: 0.87 inches
  10-Year Precipitation: 1.02 inches

- **Eager Wash A** (Storm Duration: 24 Minutes)
  5-Year Post-Burn Flow (Eq. 3): 3,150 cfs
  Estimated % Water: 80%
  2-Year Relative Increased Flash Flood Risk: High
  5-Year Relative Increased Flash Flood Risk: Extreme

10-Year Relative Increased Flash Flood Risk: Extreme
2-Year precipitation: 0.73 inches
5-Year precipitation: 0.94 inches
10-Year Precipitation: 1.10 inches

- **Drainage Area 22** (Storm Duration: 28 Minutes)
  5-Year Post-Burn Flow (Eq. 3): 6,967 cfs
  Estimated % Water: 60%
  2-Year Relative Increased Flash Flood Risk: Moderate
  5-Year Relative Increased Flash Flood Risk: High
  10-Year Relative Increased Flash Flood Risk: Extreme
  2-Year precipitation: 0.86 inches
  5-Year precipitation: 1.12 inches
  10-Year Precipitation: 1.28 inches

- **Butler Canyon** (Storm Duration: 29 Minutes)
  5-Year Post-Burn Flow (Eq. 3): 2,069 cfs
  Estimated % Water: 80%
  2-Year Relative Increased Flash Flood Risk: Moderate
  5-Year Relative Increased Flash Flood Risk: High
  10-Year Relative Increased Flash Flood Risk: Extreme
  2-Year precipitation: 0.93 inches
  5-Year precipitation: 1.20 inches
  10-Year Precipitation: 1.40 inches

- **Watts Creek** (Storm Duration: 30 Minutes)
  5-Year Post-Burn Flow (Eq. 3): 16,806 cfs
  Estimated % Water: 40%
  2-Year Relative Increased Flash Flood Risk: Extreme
  5-Year Relative Increased Flash Flood Risk: Extreme
  10-Year Relative Increased Flash Flood Risk: Extreme
  2-Year precipitation: 0.91 inches
  5-Year precipitation: 1.18 inches
  10-Year Precipitation: 1.37 inches

- **Eagar A – Wash** (Storm Duration: 30 Minutes)
  5-Year Post-Burn Flow (Eq. 3): 2,774 cfs
  Estimated % Water: 80%
  2-Year Relative Increased Flash Flood Risk: Moderate
  5-Year Relative Increased Flash Flood Risk: High
  10-Year Relative Increased Flash Flood Risk: Extreme
  2-Year precipitation: 0.80 inches
  5-Year precipitation: 1.04 inches
  10-Year Precipitation: 1.23 inches

- **Nutrioso – Watts Creek** (Storm Duration: 36 Minutes)
  5-Year Post-Burn Flow (Eq. 3): 13,143 cfs
  Estimated % Water: 40%

2-Year Relative Increased Flash Flood Risk: High
5-Year Relative Increased Flash Flood Risk: Extreme
10-Year Relative Increased Flash Flood Risk: Extreme
2-Year precipitation: 0.96 inches
5-Year precipitation: 1.24 inches
10-Year Precipitation: 1.50 inches

The 2-year precipitation for these eight basins ranges from 0.59 to 0.96 inches. The 5-year precipitation for these eight basins ranges from 0.78 to 1.24 inches. The 10-year precipitation for these eight basins ranges from 0.92 to 1.50 inches. The storm durations for these eight basins ranges from 13 to 36 minutes.

REFERENCES

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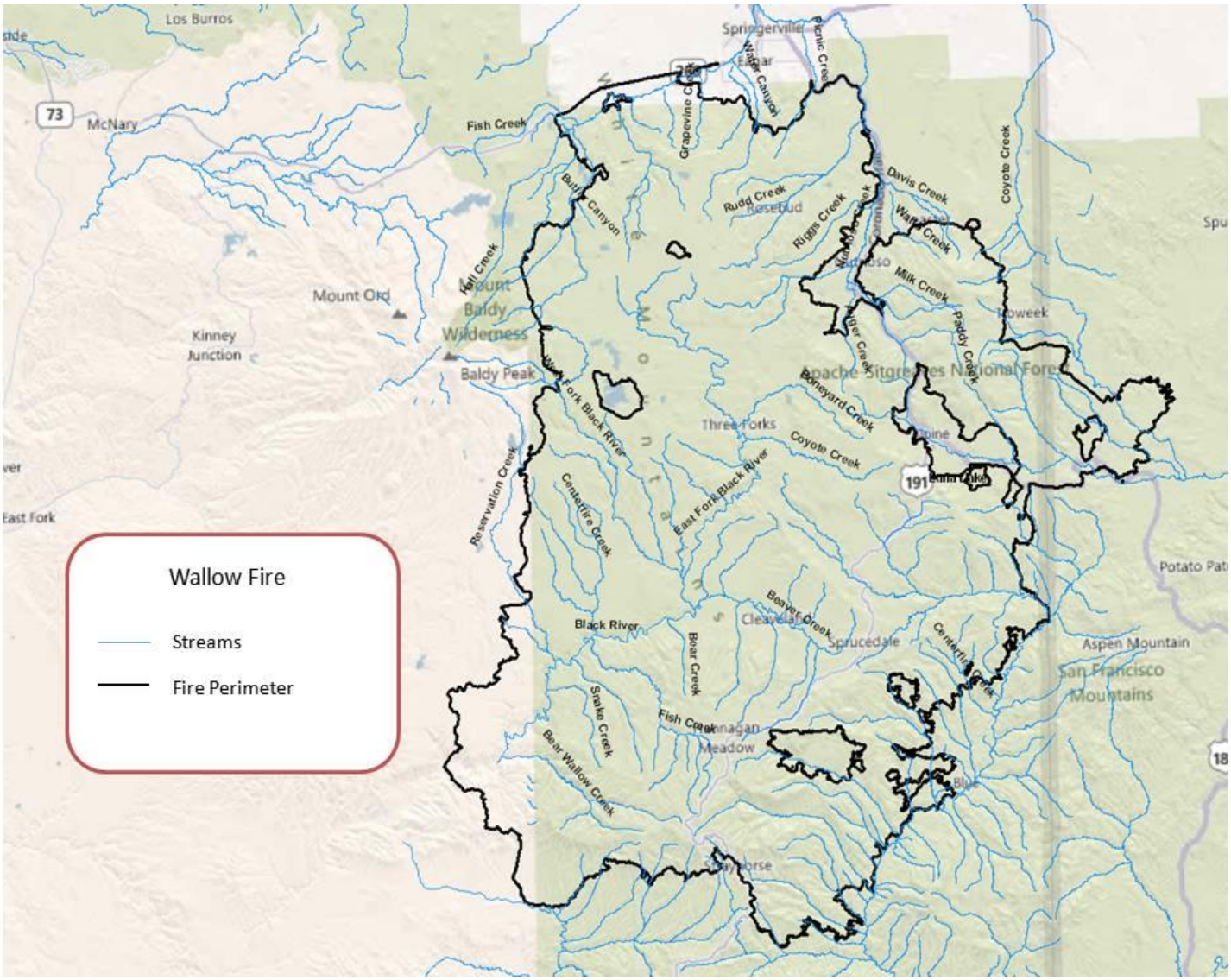
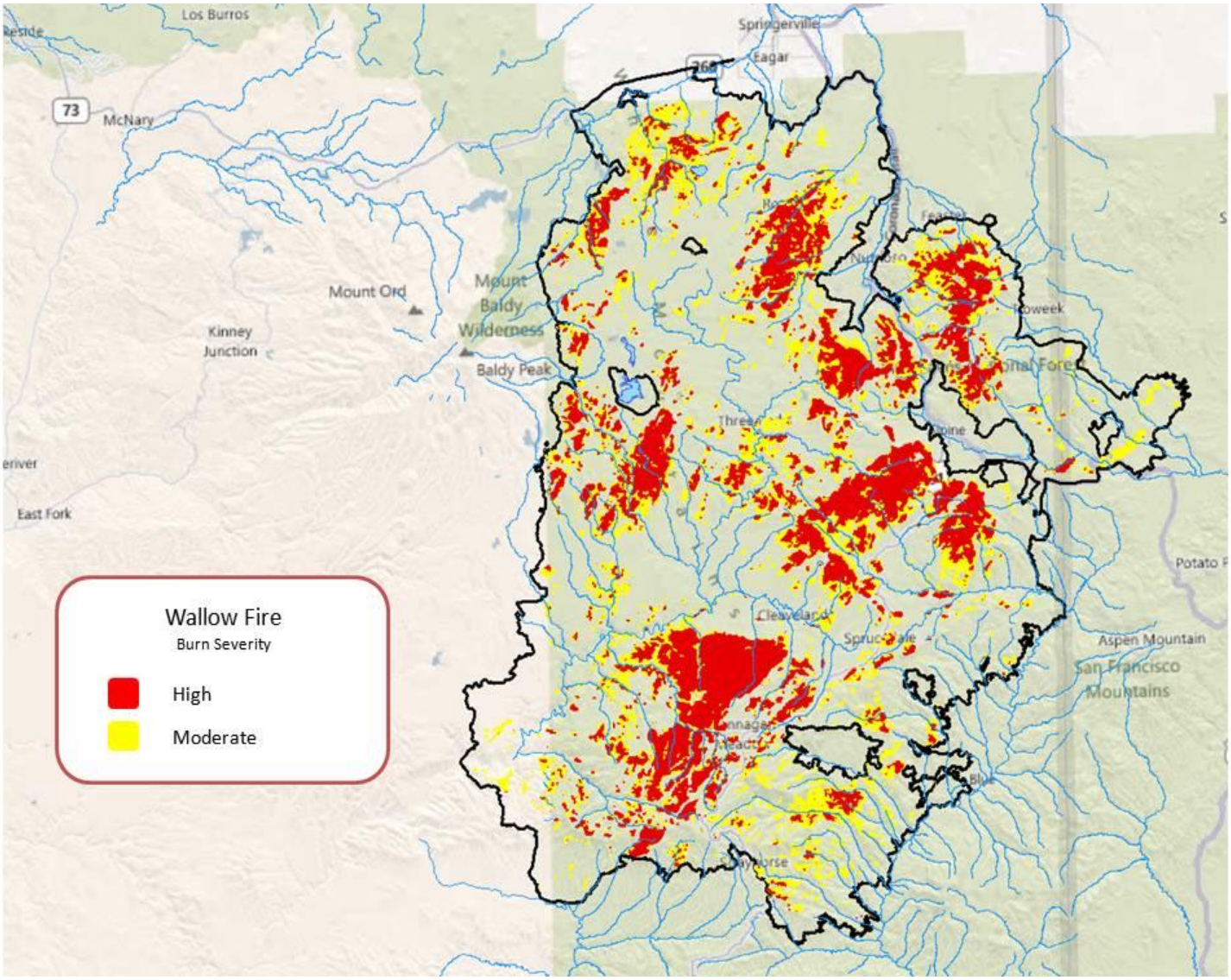
WALLOW FIRE FIGURE 1. SELECTED STREAMS



WALLOW FIRE FIGURE 2. HIGH AND MODERATE BURN SEVERITY



WALLOW FIRE FIGURE 3. SELECTED BASIN VALUES							
	Drainage Area (sq. mi.)	Hyper-Effective Drainage Area (sq. mi.)	Rise (ft.)	Maximum Basin Elevation (ft.)	Mean Basin Elevation (ft./1000)	Channel Relief Ratio[1]	Storm Duration (minutes)
Butler Canyon	1.22	0.56	1083	9393	8.9	0.084	29
Robert Odell	1.88	1.44	1437	9511	8.8	0.059	55
Home by Colter Creek	14.09	9.67	1673	9662	8.8	0.048	78
Watts Creek	3.98	2.70	3235	10906	9.3	0.173	30
Milk Creek - Terry Ranch	5.49	4.25	2768	10588	9.2	0.099	50
Casita Escondia	4.70	2.30	1965	9806	8.8	0.102	37
Eager Wash A	1.35	0.40	1158	8399	7.8	0.105	24
Slade Reservoir 2	1.06	0.09	1211	8642	8.0	0.148	17
Grapevine Residence	4.39	1.67	2008	9249	8.2	0.094	41
Water Canyon Admin Site	10.24	1.55	2077	9567	8.5	0.042	106
John May Reservoir	4.25	1.60	2870	10787	9.4	0.105	48
Hussey Creek	2.65	1.04	2627	10449	9.1	0.117	39
Data Range	**1.1-14.1**	**0.1-9.7**	**1,083-3,235**	**8,399-10,906**	**7.8-9.4**	**0.04-0.17**	**17-106**

[1] Used channel relief ratio unmodified.

WALLOW FIRE FIGURE 4. SELECTED BASIN VALUES

	Drainage Area (sq. mi.)	Hyper-Effective Drainage Area (sq. mi.)	Rise (ft.)	Maximum Basin Elevation (ft.)	Mean Basin Elevation (ft./1000)	Channel Relief Ratio[2]	Storm Duration (minutes)
Auger Creek	14.71	5.87	1260	8901	8.3	0.035	89
Bear Creek-Black River	22.57	11.19	2274	9170	8.0	0.040	120
Bear Wallow Creek	23.77	6.84	2720	9134	7.8	0.044	126
Boneyard Creek	20.76	7.34	1020	9236	8.7	0.019	157
Centerfire Creek	28.09	6.36	1991	8881	7.9	0.037	118
Colter Creek	16.02	6.71	1575	9160	8.4	0.030	126
Coyote Creek	16.41	7.68	1030	9163	8.6	0.020	148
East Fork Black River	28.85	8.81	1581	9055	8.3	0.016	262
East Fork Little Colorado River	14.01	2.96	1598	9957	9.2	0.028	138
Fish Creek	25.59	15.72	2343	9239	8.1	0.030	171
Fish Creek - Little Colorado River	21.16	0.03	2185	9560	8.5	0.032	153
Hall Creek - Little Colorado River	32.12	1.77	2113	9918	8.9	0.035	135
Lower Beaver Creek	26.27	7.96	1972	9272	8.3	0.039	111
Lower West Fork Black River	26.69	9.31	1529	9003	8.2	0.026	146
North Fork East Fork Black River	45.92	4.18	1063	9278	8.7	0.011	295
Pacheta Creek	36.48	0.33	3173	9639	8.1	0.031	214
Paddy Creek	22.90	10.84	1683	7776	6.9	0.038	102
Picnic Creek - Nutrioso Creek	26.61	0.63	1647	8560	7.7	0.026	154
Reservation Creek	25.68	0.83	3474	10230	8.5	0.035	195
Riggs Creek - Nutrioso Creek	34.22	8.45	1791	9154	8.3	0.024	179
Rudd Creek	27.72	10.47	1739	9101	8.2	0.025	171
Snake Creek - Black River	29.39	6.92	2119	8586	7.5	0.024	208
South Fork Little Colorado River	25.33	9.29	1795	9170	8.3	0.028	155
Upper Beaver Creek	37.33	11.63	1483	9078	8.3	0.023	165
Upper West Fork Black River	33.67	8.59	2982	10853	9.4	0.038	158
West Fork Little Colorado River	12.71	1.10	2221	10581	9.5	0.044	108
Yellow Pine Tank - Black R.	37.62	1.56	1424	7516	6.8	0.017	234
Data Range	**12.7-45.9**	**0.03-15.72**	**1,020-3,474**	**7,516-10,853**	**6.8-9.5**	**0.01-0.04**	**89-295**

[2] Used channel relief ratio unmodified.

WALLOW FIRE FIGURE 5. SELECTED BASIN VALUES							
	Drainage Area (sq. mi.)	Hyper-Effective Drainage Area (sq. mi.)	Rise (ft.)	Maximum Basin Elevation (ft.)	Mean Basin Elevation (ft./1000)	Channel Relief Ratio[3]	Storm Duration (minutes)
Eagar A-Wash	1.56	0.42	1361	8398	7.7	0.096	30
Drainage Area 19	2.21	1.18	1571	9810	9.0	0.220	13
Drainage Area 22	4.19	1.55	1836	10089	9.2	0.124	28
Nutrioso - Watts Creek	4.88	2.90	3348	10907	9.2	0.148	36
Eagar Dry Wash	6.46	0.96	1966	9019	8.0	0.060	68
Nutrioso - Davis/Wood Creeks	6.90	2.12	2906	10789	9.3	0.109	46
Picnic Creek	8.82	0.63	1716	8796	7.9	0.042	92
Auger Creek	9.41	5.54	1836	9579	8.7	0.073	52
Eagar Water Canyon	19.32	2.62	2551	9569	8.3	0.035	155
Nutrioso Creek	21.46	11.44	3263	10907	9.3	0.061	99
Alpine	22.00	6.15	2158	10089	9.0	0.062	70
Southfork	25.36	9.90	2381	9763	8.6	0.040	126
Greer U/S River Reservoir	30.42	4.87	3186	11417	9.8	0.051	120
Luna Lake	32.42	8.57	2203	10089	9.0	0.043	109
Data Range	**1.6-32.4**	**0.4-11.4**	**1,361-3,348**	**8,398-11,417**	**7.7-9.8**	**0.04-0.22**	**13-155**

[3] Used channel relief ratio unmodified.

WALLOW FIRE FIGURE 6. RESULTS FOR 2-YEAR FLASH FLOODS					
	Pre-Burn USGS Eq. (cfs)	**Post-Burn Eq. 3 + (cfs)**	**Post-Burn / Pre-Burn Ratio**	**Post-Burn Basin Yield (cfs/sq. mi.)**	**Relative Increased Flash Flood Risk**
Butler Canyon	38	**996**	25.9	816	Moderate
Robert Odell	50	**821**	16.4	437	Moderate
Home by Colter Creek	163	**1491**	9.2	106	Moderate
Watts Creek	61	**8211**	134.2	2064	Extreme
Milk Creek - Terry Ranch	89	**3600**	40.7	656	Moderate
Casita Escondia	85	**2964**	34.7	631	Moderate
Eager Wash A	48	**1524**	31.7	1128	High
Slade Reservoir 2	40	**1340**	33.4	1265	High
Grapevine Residence	90	**2379**	26.6	542	Moderate
Water Canyon Admin Site	141	**588**	4.2	57	Low
John May Reservoir	75	**2440**	32.7	574	Moderate
Hussey Creek	58	**2475**	42.5	935	Moderate
Range		**588-8,211**	**4.2-134.2**		

WALLOW FIRE FIGURE 7. RESULTS FOR 2-YEAR FLASH FLOODS

	Pre-Burn USGS Eq. (cfs)	Post-Burn Eq. 3 + (cfs)	Post-Burn / Pre-Burn Ratio	Post-Burn Basin Yield (cfs/sq. mi.)	Relative Increased Flash Flood Risk
Auger Creek	182	**788**	4.3	54	Low
Bear Creek-Black River	243	**1390**	5.7	62	Low
Bear Wallow Creek	261	**1373**	5.3	58	Low
Boneyard Creek	208	**347**	1.7	17	Low
Centerfire Creek	283	**1058**	3.7	38	Low
Colter Creek	188	**643**	3.4	40	Low
Coyote Creek	183	**343**	1.9	21	Low
East Fork Black River	270	**374**	1.4	13	Low
East Fork Little Colorado River	155	**398**	2.6	28	Low
Fish Creek	260	**963**	3.7	38	Low
Fish Creek - Little Colorado River	218	**255**	1.2	12	Low
Hall Creek - Little Colorado River	263	**574**	2.2	18	Low
Lower Beaver Creek	255	**1146**	4.5	44	Low
Lower West Fork Black River	259	**654**	2.5	24	Low
North Fork East Fork Black River	330	**359**	1.1	8	Low
Pacheta Creek	321	**441**	1.4	12	Low
Paddy Creek	296	**1499**	5.1	65	Low
Picnic Creek - Nutrioso Creek	281	**409**	1.5	15	Low
Reservation Creek	244	**477**	2.0	19	Low
Riggs Creek - Nutrioso Creek	299	**629**	2.1	18	Low
Rudd Creek	265	**632**	2.4	23	Low
Snake Creek - Black River	309	**632**	2.0	22	Low
South Fork Little Colorado River	250	**695**	2.8	27	Low
Upper Beaver Creek	311	**636**	2.0	17	Low
Upper West Fork Black River	252	**1002**	4.0	30	Low
West Fork Little Colorado River	140	**493**	3.5	39	Low
Yellow Pine Tank - Black R.	407	**495**	1.2	13	Low
Range		**255-1,499**	**1.1-5.7**		

WALLOW FIRE FIGURE 8. RESULTS FOR 2-YEAR FLASH FLOODS					
	Pre-Burn USGS Eq. (cfs)	**Post-Burn Eq. 3 + (cfs)**	**Post-Burn / Pre-Burn Ratio**	**Post-Burn Basin Yield (cfs/sq. mi.)**	**Relative Increased Flash Flood Risk**
Eagar A - Wash	34	**1325**	39	851	Moderate
Drainage Area 19	43	**8833**	208	3992	Extreme
Drainage Area 22	77	**3376**	44	805	Moderate
Nutrioso - Watts Creek	70	**6406**	92	1311	High
Eagar Dry Wash	83	**850**	10	132	Moderate
Nutrioso - Davis/Wood Creeks	86	**3045**	35	441	Moderate
Picnic Creek	100	**418**	4	47	Low
Auger Creek	104	**2525**	24	268	Moderate
Eagar Water Canyon	163	**579**	4	30	Low
Nutrioso Creek	174	**2408**	14	112	Moderate
Alpine	213	**1989**	9	90	Low
Southfork	193	**1190**	6	47	Low
Greer U/S River Reservoir	216	**1172**	5	39	Low
Luna Lake	268	**1276**	5	39	Low
Range		**418-8,833**	**4-208**		

WALLOW FIRE FIGURE 9. RESULTS FOR 5-YEAR FLASH FLOODS					
	Pre-Burn USGS Eq. (cfs)	**Post-Burn Eq. 3 + (cfs)**	**Post-Burn / Pre-Burn Ratio**	**Post-Burn Basin Yield (cfs/sq. mi.)**	**Relative Increased Flash Flood Risk**
Butler Canyon	145	**2069**	14.2	1695	High
Robert Odell	185	**1695**	9.2	903	Moderate
Home by Colter Creek	572	**3118**	5.5	221	Moderate
Watts Creek	282	**16806**	59.7	4225	Extreme
Milk Creek - Terry Ranch	337	**7383**	21.9	1346	High
Casita Escondia	309	**6118**	19.8	1303	High
Eager Wash A	154	**3150**	20.5	2330	Extreme
Slade Reservoir 2	134	**2782**	20.7	2626	Extreme
Grapevine Residence	298	**4927**	16.6	1123	High
Water Canyon Admin Site	478	**1361**	2.8	133	Moderate
John May Reservoir	292	**5066**	17.3	1192	High
Hussey Creek	224	**5116**	22.8	1932	High
Range		**1,361-16,806**	**2.8-59.7**		

WALLOW FIRE FIGURE 10. RESULTS FOR 5-YEAR FLASH FLOODS					
	Pre-Burn USGS Eq. (cfs)	**Post-Burn Eq. 3 + (cfs)**	**Post-Burn / Pre-Burn Ratio**	**Post-Burn Basin Yield (cfs/sq. mi.)**	**Relative Increased Flash Flood Risk**
Auger Creek	586	**1737**	3.0	118	Moderate
Bear Creek-Black River	745	**2963**	4.0	131	Moderate
Bear Wallow Creek	767	**2969**	3.9	125	Moderate
Boneyard Creek	710	**894**	1.3	43	Low
Centerfire Creek	842	**2363**	2.8	84	Low
Colter Creek	614	**1447**	2.4	90	Low
Coyote Creek	623	**832**	1.3	51	Low
East Fork Black River	854	**974**	1.1	34	Low
East Fork Little Colorado River	570	**1012**	1.8	72	Low
Fish Creek	799	**2069**	2.6	81	Low
Fish Creek - Little Colorado River	718	**793**	1.1	37	Low
Hall Creek - Little Colorado River	907	**1521**	1.7	47	Low
Lower Beaver Creek	811	**2540**	3.1	97	Low
Lower West Fork Black River	818	**1522**	1.9	57	low
North Fork East Fork Black River	1108	**1127**	1.0	25	Low
Pacheta Creek	974	**1217**	1.2	33	Low
Paddy Creek	751	**3136**	4.2	137	Moderate
Picnic Creek - Nutrioso Creek	817	**1072**	1.3	40	Low
Reservation Creek	800	**1266**	1.6	49	Low
Riggs Creek - Nutrioso Creek	940	**1532**	1.6	45	Low
Rudd Creek	835	**1472**	1.8	53	Low
Snake Creek - Black River	863	**1469**	1.7	50	Low
South Fork Little Colorado River	794	**1598**	2.0	63	Low
Upper Beaver Creek	987	**1541**	1.6	41	Low
Upper West Fork Black River	932	**2355**	2.5	70	Low
West Fork Little Colorado River	540	**1237**	2.3	97	Low
Yellow Pine Tank - Black R.	991	**1164**	1.2	31	Low
Range		**832-3,136**	**1.0-4.2**		

WALLOW FIRE FIGURE 11. RESULTS FOR 5-YEAR FLASH FLOODS					
	Pre-Burn USGS Eq. (cfs)	**Post-Burn Eq. 3 + (cfs)**	**Post-Burn / Pre-Burn Ratio**	**Post-Burn Basin Yield (cfs/sq. mi.)**	**Relative Increased Flash Flood Risk**
Eagar A - Wash	167	**2774**	16.6	1781	High
Drainage Area 19	203	**18080**	89.1	8171	Extreme
Drainage Area 22	279	**6967**	25.0	1662	High
Nutrioso - Watts Creek	316	**13143**	41.6	2690	Extreme
Eagar Dry Wash	370	**1906**	5.2	295	Moderate
Nutrioso - Davis/Wood Creeks	383	**6357**	16.6	921	Moderate
Picnic Creek	440	**1070**	2.4	121	Moderate
Auger Creek	456	**5252**	11.5	558	Moderate
Eagar Water Canyon	683	**1484**	2.2	77	Low
Nutrioso Creek	724	**5085**	7.0	237	Moderate
Alpine	682	**4236**	6.2	193	Moderate
Southfork	795	**2672**	3.4	105	Moderate
Greer U/S River Reservoir	880	**2760**	3.1	91	Low
Luna Lake	837	**2817**	3.4	87	Low
Range		**1,070-18,080**	**2.4-89.1**		

WALLOW FIRE FIGURE 12. RESULTS FOR 10-YEAR FLASH FLOODS					
	Pre-Burn USGS Eq. (cfs)	**Post-Burn Eq. 3 + (cfs)**	**Post-Burn / Pre-Burn Ratio**	**Post-Burn Basin Yield (cfs/sq. mi.)**	**Relative Increased Flash Flood Risk**
Butler Canyon	396	**3627**	9.2	2973	Extreme
Robert Odell	483	**2946**	6.1	1570	High
Home by Colter Creek	1232	**5426**	4.4	385	Moderate
Watts Creek	350	**28785**	82.2	7236	Extreme
Milk Creek - Terry Ranch	795	**12712**	16.0	2317	Extreme
Casita Escondia	740	**10600**	14.3	2258	Extreme
Eager Wash A	415	**5509**	13.3	4076	Extreme
Slade Reservoir 2	371	**4899**	13.2	4625	Extreme
Grapevine Residence	717	**8578**	12.0	1955	High
Water Canyon Admin Site	1062	**2540**	2.4	248	Moderate
John May Reservoir	706	**8817**	12.5	2075	Extreme
Hussey Creek	567	**8886**	15.7	3355	Extreme
Range		**2,540-28,785**	**2.4-82.2**		

WALLOW FIRE FIGURE 13. RESULTS FOR 10-YEAR FLASH FLOODS

	Pre-Burn USGS Eq. (cfs)	Post-Burn Eq. 3 + (cfs)	Post-Burn / Pre-Burn Ratio	Post-Burn Basin Yield (cfs/sq. mi.)	Relative Increased Flash Flood Risk
Auger Creek	1257	**3130**	2.5	213	Moderate
Bear Creek - Black River	1533	**5211**	3.4	231	Moderate
Bear Wallow Creek	1570	**5275**	3.4	222	Moderate
Boneyard Creek	1475	**1698**	1.2	82	Low
Centerfire Creek	1697	**4249**	2.5	151	Moderate
Colter Creek	1307	**2629**	2.0	164	Moderate
Coyote Creek	1322	**1562**	1.2	95	Low
East Fork Black River	1718	**1846**	1.1	64	Low
East Fork Little Colorado River	1229	**1934**	1.6	138	Moderate
Fish Creek	1625	**3647**	2.2	143	Moderate
Fish Creek - Little Colorado River	1488	**1616**	1.1	76	Low
Hall Creek - Little Colorado River	1806	**2845**	1.6	89	Low
Lower Beaver Creek	1645	**4535**	2.8	173	Moderate
Lower West Fork Black River	1657	**2776**	1.7	104	Moderate
North Fork East Fork Black River	2131	**2143**	1.0	47	Low
Pacheta Creek	1916	**2330**	1.2	64	Low
Paddy Creek	1543	**5514**	3.6	241	Moderate
Picnic Creek - Nutrioso Creek	1655	**2087**	1.3	78	Low
Reservation Creek	1628	**2418**	1.5	94	Low
Riggs Creek - Nutrioso Creek	1860	**2814**	1.5	82	Low
Rudd Creek	1686	**2683**	1.6	97	Low
Snake Creek - Black River	1733	**2713**	1.6	92	Low
South Fork Little Colorado River	1617	**2902**	1.8	115	Moderate
Upper Beaver Creek	1936	**2811**	1.5	75	Low
Upper West Fork Black River	1846	**4225**	2.3	125	Moderate
West Fork Little Colorado River	1174	**2349**	2.0	185	Moderate
Yellow Pine Tank - Black R.	1943	**2229**	1.1	59	Low
Range		**1,562-5,514**	**1.0-3.6**		

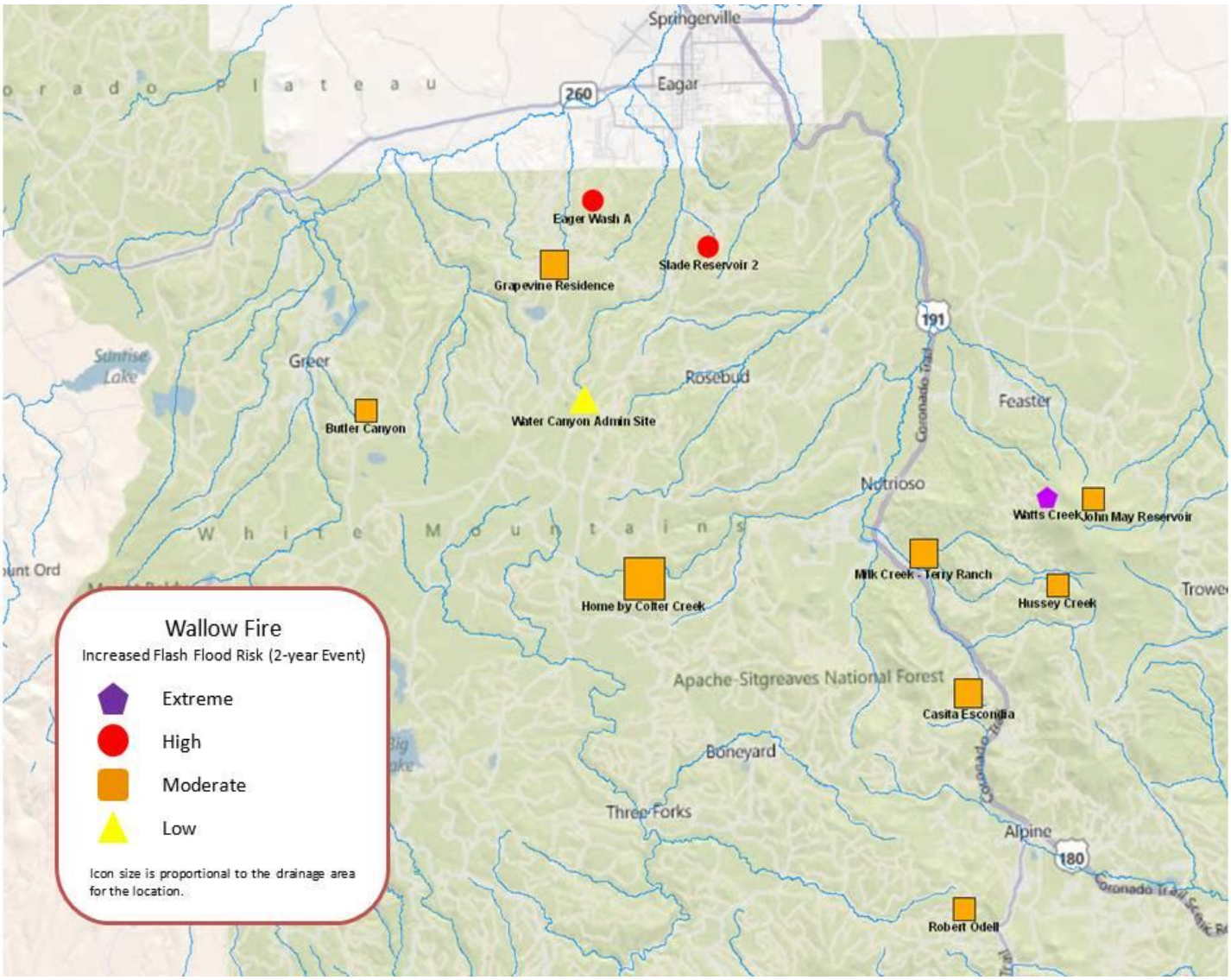
WALLOW FIRE FIGURE 14. RESULTS FOR 10-YEAR FLASH FLOODS					
	Pre-Burn USGS Eq. (cfs)	**Post-Burn Eq. 3 + (cfs)**	**Post-Burn / Pre-Burn Ratio**	**Post-Burn Basin Yield (cfs/sq. mi.)**	**Relative Increased Flash Flood Risk**
Eagar A - Wash	244	**4727**	19.4	3035	Extreme
Drainage Area 19[4]	242	**30963**	128.0	13994	Extreme
Drainage Area 22	702	**12092**	17.2	2884	Extreme
Nutrioso - Watts Creek	365	**22471**	61.6	4600	Extreme
Eagar Dry Wash	511	**3164**	6.2	490	Moderate
Nutrioso - Davis/Wood Creeks	437	**10751**	24.6	1558	High
Picnic Creek	656	**1745**	2.7	198	Moderate
Auger Creek	513	**8898**	17.3	946	Moderate
Eagar Water Canyon	924	**2331**	2.5	121	Moderate
Nutrioso Creek	788	**8511**	10.8	397	Moderate
Alpine	1515	**7515**	5.0	342	Moderate
Southfork	1040	**4387**	4.2	173	Moderate
Greer U/S River Reservoir	993	**4301**	4.3	141	Moderate
Luna Lake	1814	**5110**	2.8	158	Moderate
Range		**1,745-30,963**	**2.5-128.0**		

[4] The 10-year post-burn peak flow for Drainage Area 19 is greater than (18,000 cfs) the potential maximum peak floodflow estimated for the basin using the envelope curve for region 16 developed by Crippen and Bue (1977). However, 40% of the peak flow (the estimated percent water of the peak flow) is 12,385 cfs.

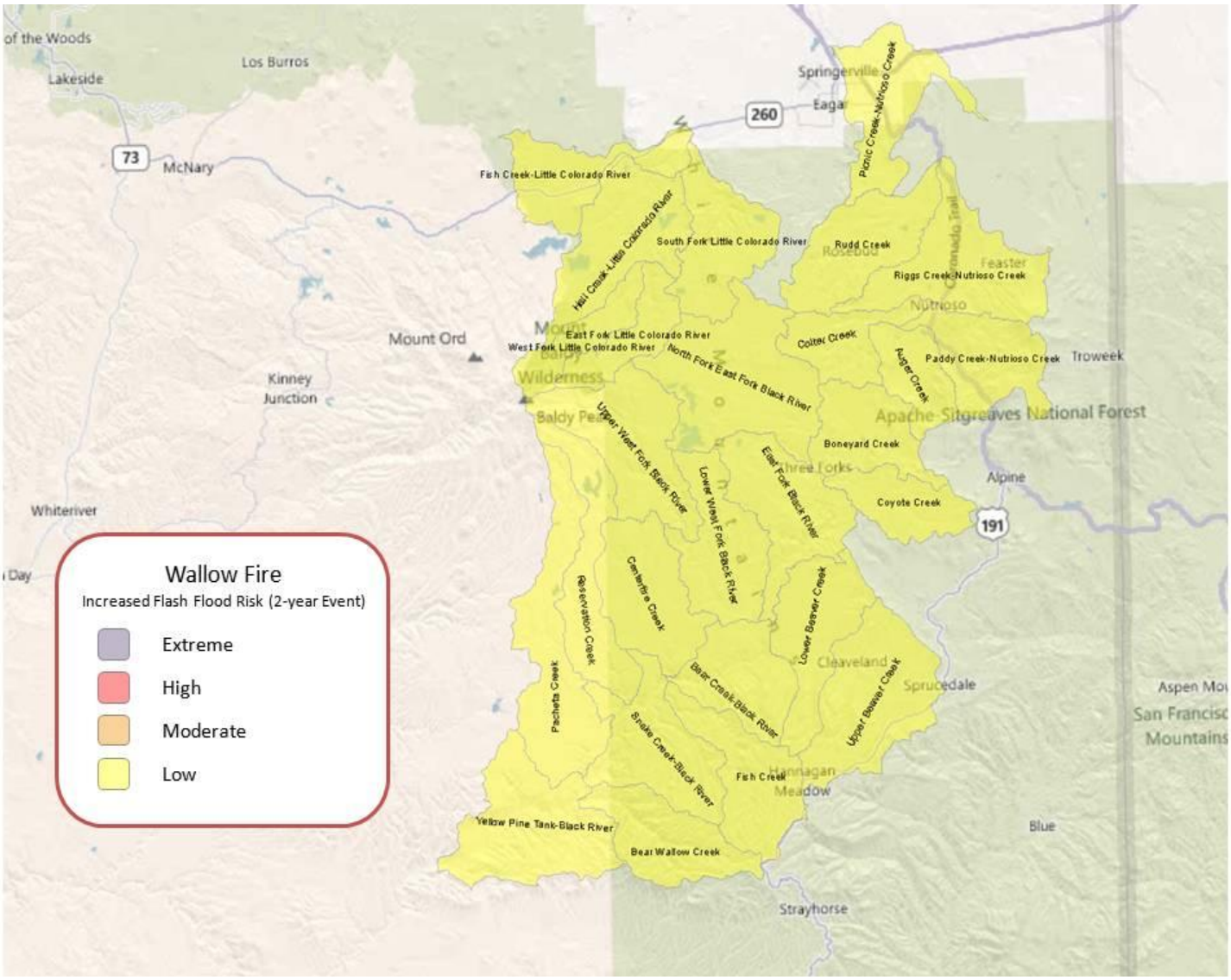
WALLOW FIRE FIGURE 15. HYPER-CONCENTRATED FLOWS

	Multivariate Index	est. % water
Drainage Area 19	12.70818	40%
Watts Creek	11.80932	40%
Nutrioso - Watts Creek	9.189478	40%
Milk Creek – Terry Ranch	5.153323	60%
Drainage Area 22	4.789016	60%
Nutrioso - Davis/Wood Creeks	4.294861	60%
Casita Escondia	4.202007	60%
Auger Creek	3.569271	60%
Hussey Creek	3.508958	60%
John May Reservoir	3.441442	60%
Nutrioso Creek	3.345465	60%
Grapevine Residence	3.341635	60%
Alpine	2.637479	60%
Eager Wash A	2.141395	80%
Home by Colter Creek	2.0685	80%
Paddy Creek	1.92934	80%
Slade Reservoir 2	1.871611	80%
Eagar A Wash	1.867023	80%
Bear Creek - Black River	1.820985	80%
Bear Wallow Creek	1.705214	80%
Luna Lake	1.548776	80%
Southfork	1.539224	80%
Greer U/S River Reservoir	1.421842	80%
Butler Canyon	1.399744	80%
Lower Beaver Creek	1.389514	80%
Fish Creek	1.23851	80%
Centerfire Creek	1.203786	80%
Upper West Fork Black River	1.168405	80%
Robert Odell	1.161045	80%
Eagar Dry Wash	1.118954	80%
Auger Creek	0.973285	80%
South Fork Little Colorado River	0.769095	80%
Colter Creek	0.765831	80%
Lower West Fork Black River	0.695088	90%
Water Canyon Admin. Site	0.670787	90%
Rudd Creek	0.669105	90%
Eagar Water Canyon	0.627549	90%
Upper Beaver Creek	0.605096	90%
Riggs Creek - Nutrioso Creek	0.578936	90%
Snake Creek - Black River	0.568135	90%
West Fork Little Colorado River	0.522704	90%
Hall Creek - Little Colorado River	0.465884	100%
Picnic Creek	0.464779	100%
East Fork Little Colorado River	0.394679	100%
Coyote Creek	0.351176	100%
Reservation Creek	0.344766	100%
Boneyard Creek	0.30455	100%
East Fork Black River	0.266881	100%
Picnic Creek - Nutrioso Creek	0.192596	100%
Pacheta Creek	0.176424	100%
Yellow Pine Tank - Black R.	0.149438	100%
North Fork East Fork Black River	0.084009	100%
Fish Creek - Little Colorado River	0.05292	100%

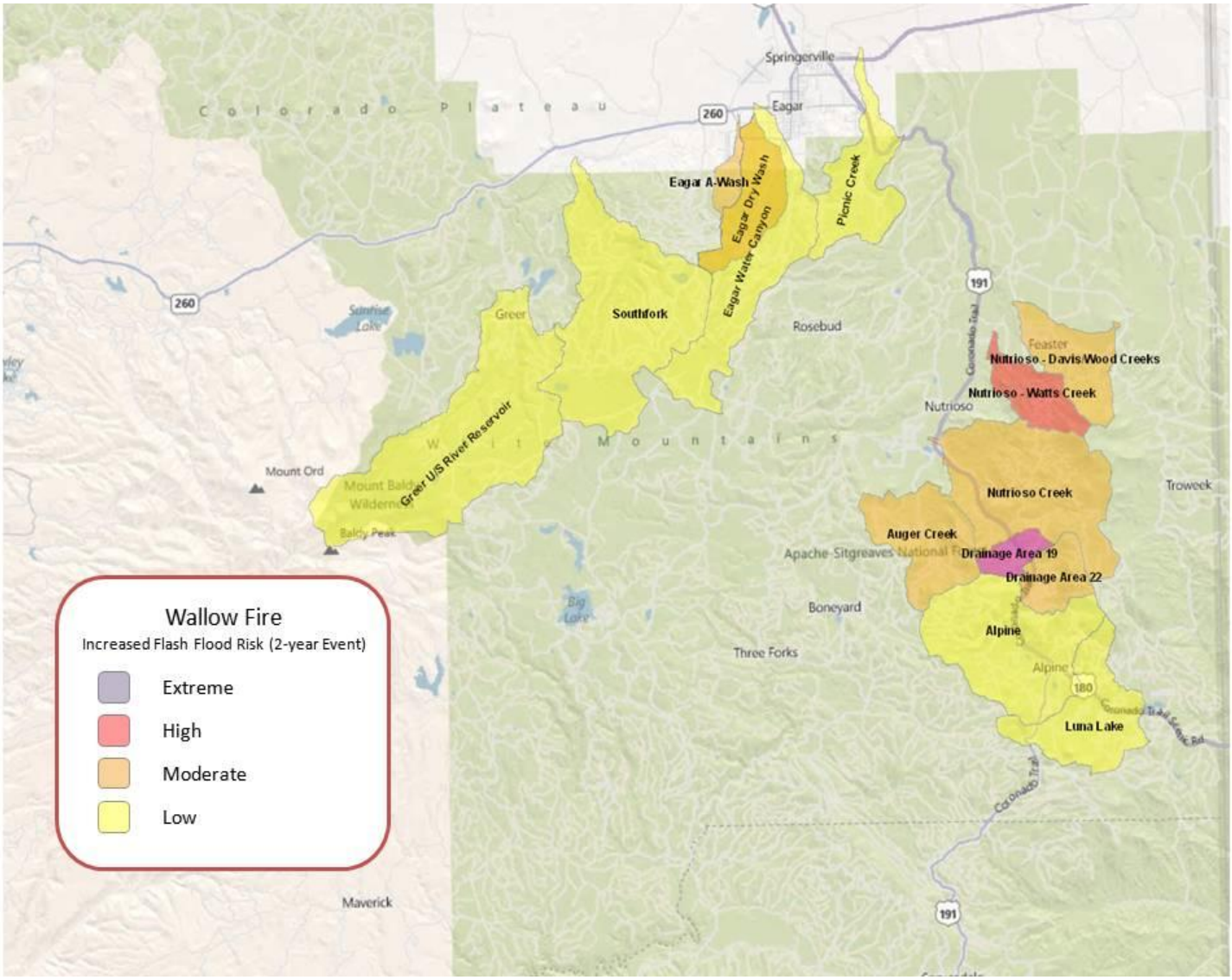
WALLOW FIRE FIGURE 16. INCREASED FLASH FLOOD RISK 2-YEAR - WILDCAT 5



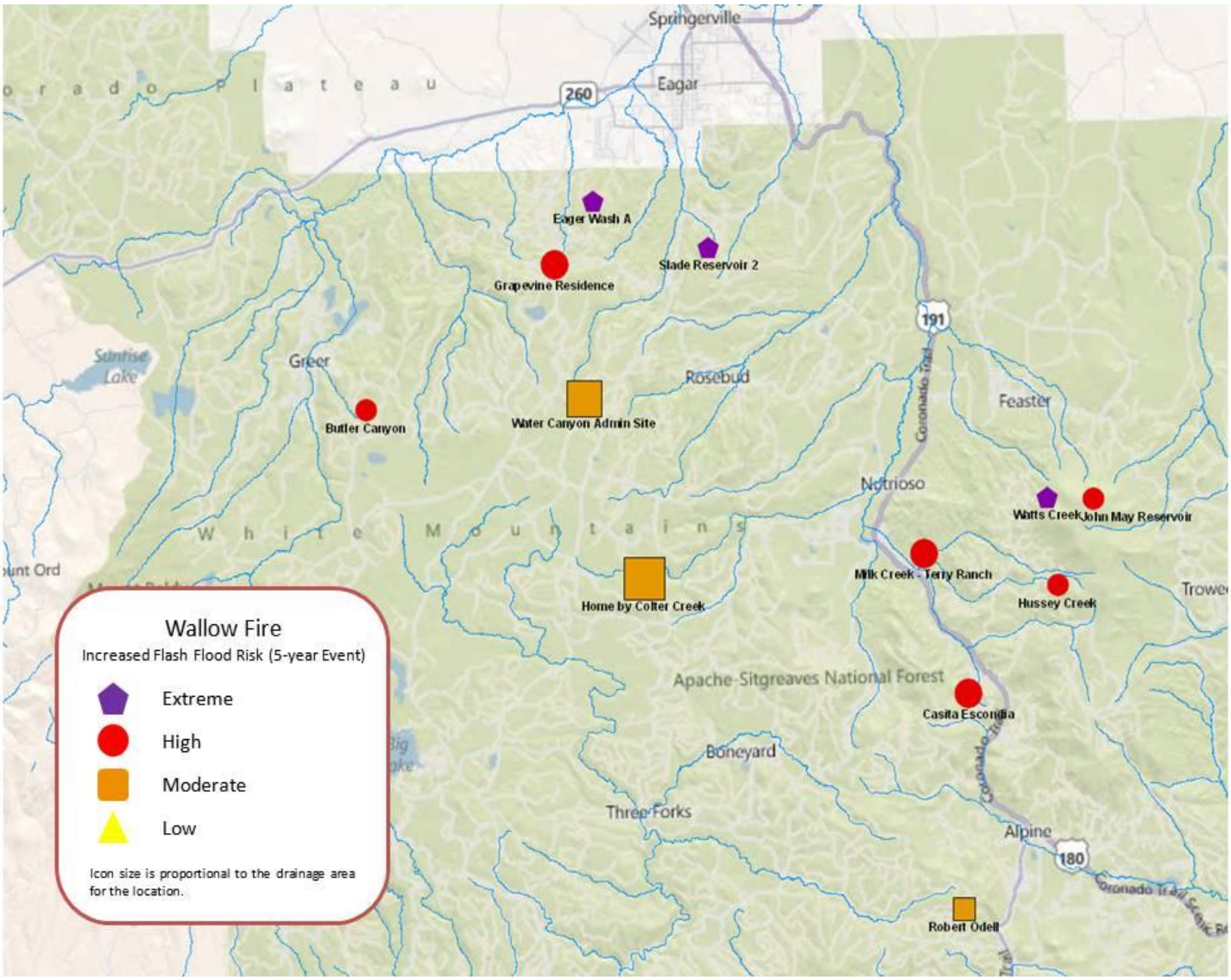
WALLOW FIRE FIGURE 17. INCREASED FLASH FLOOD RISK 2-YEAR - HEC-RAS



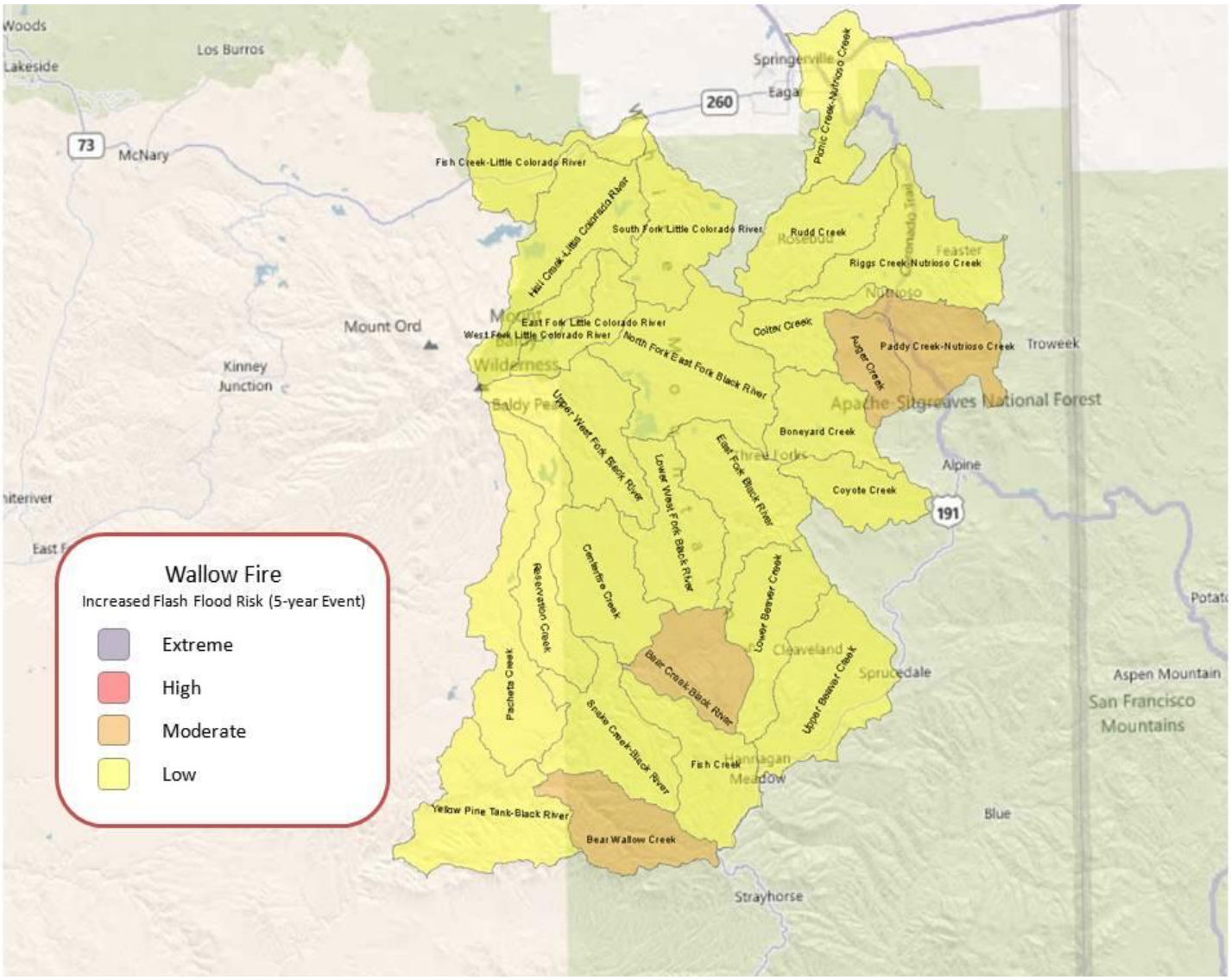
WALLOW FIRE FIGURE 18. INCREASED FLASH FLOOD RISK 2-YEAR - APACHE COUNTY



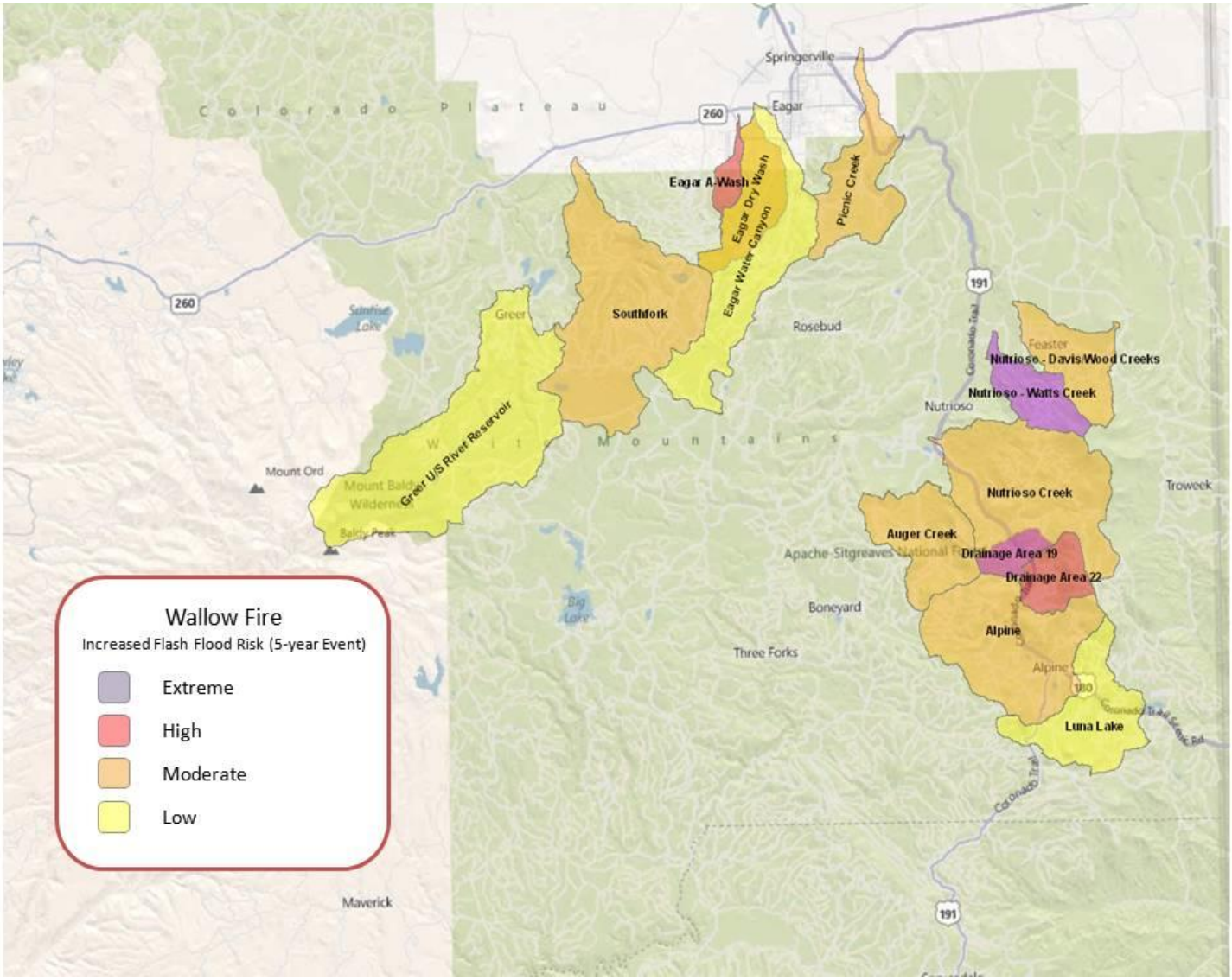
WALLOW FIRE FIGURE 19. INCREASED FLASH FLOOD RISK 5-YEAR – WILDCAT 5



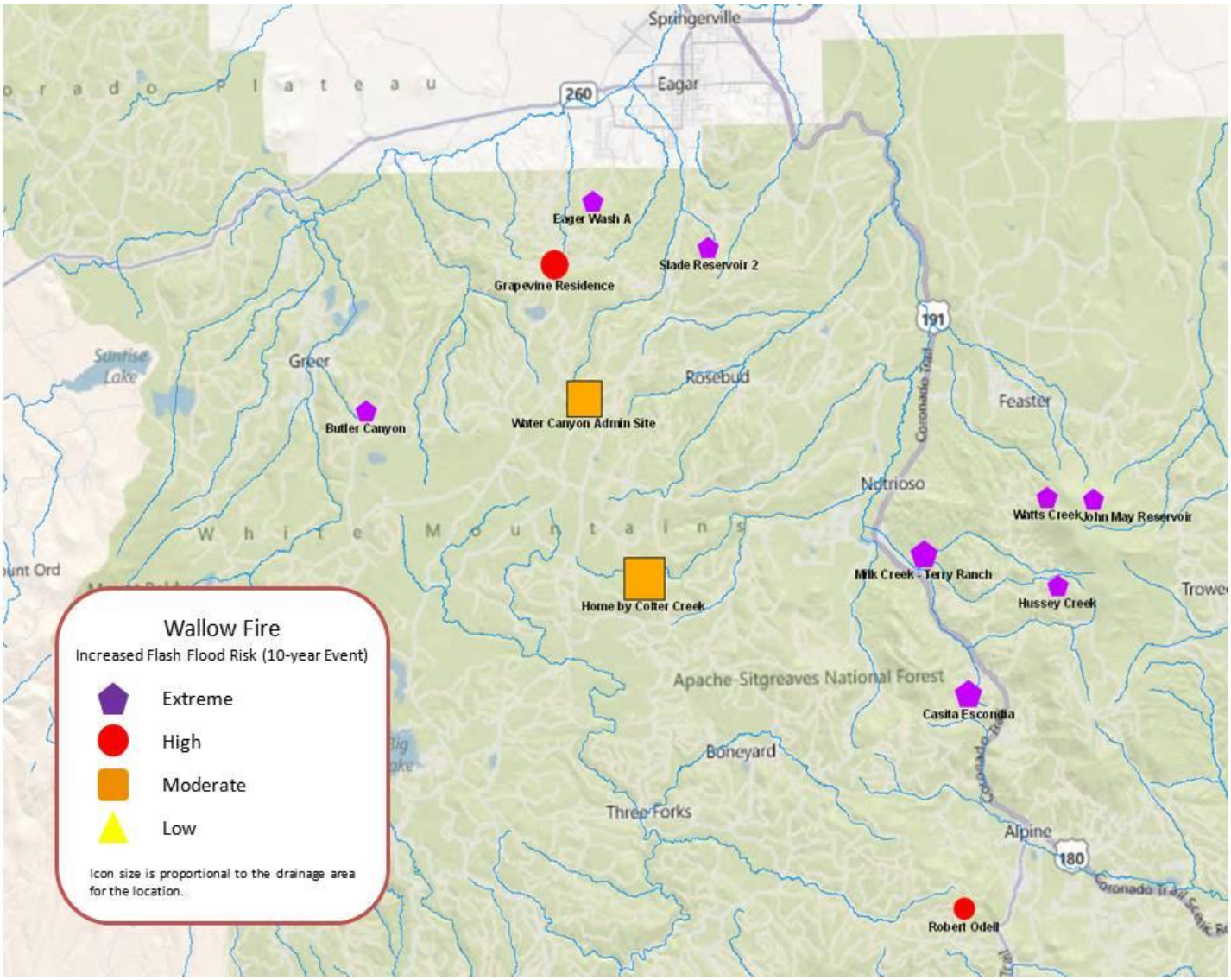
WALLOW FIRE FIGURE 20. INCREASED FLASH FLOOD RISK 5-YEAR – HEC-RAS



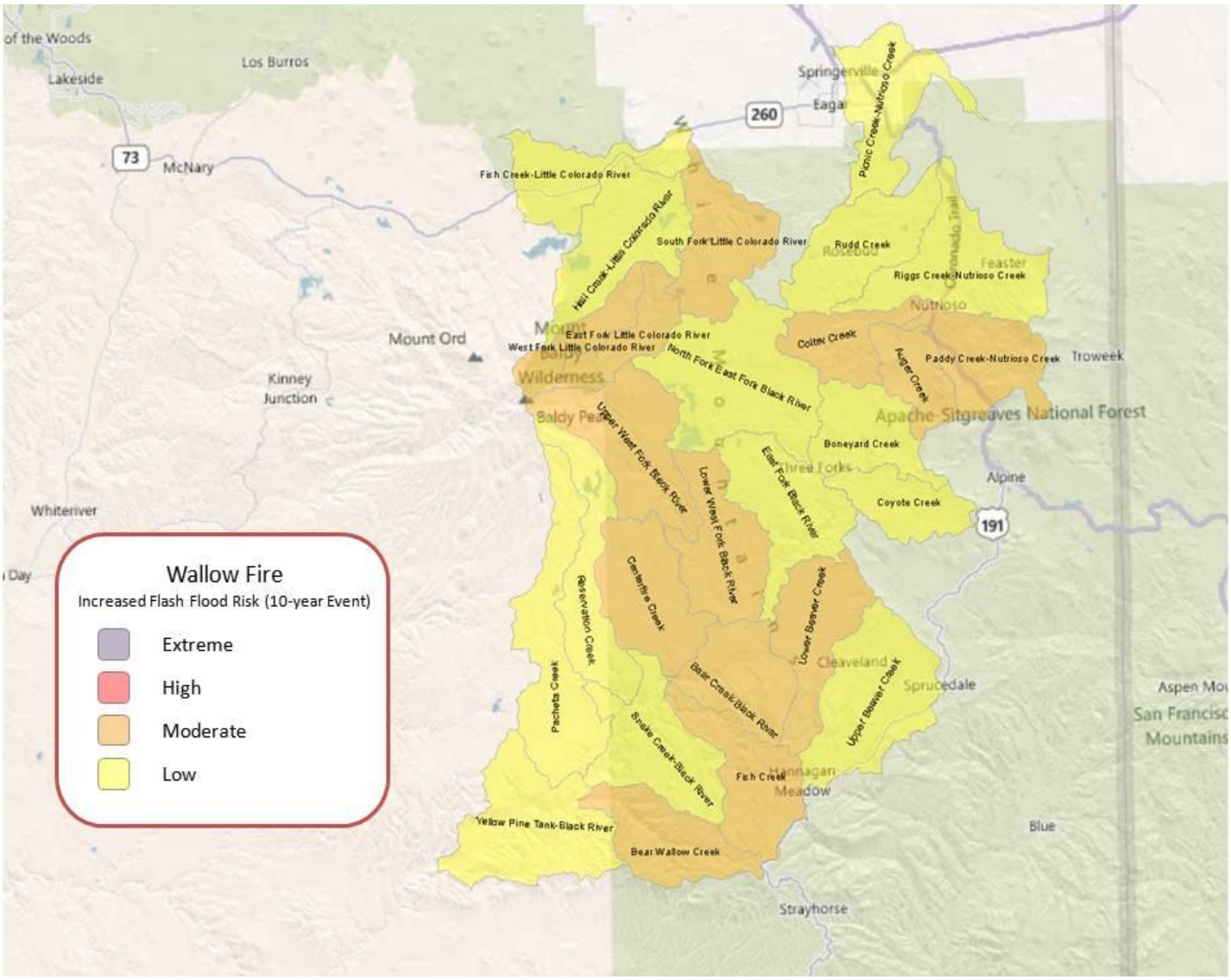
WALLOW FIRE FIGURE 21. INCREASED FLASH FLOOD RISK 5-YEAR – APACHE COUNTY



WALLOW FIRE FIGURE 22. INCREASED FLASH FLOOD RISK 10-YEAR - WILDCAT 5



WALLOW FIRE FIGURE 23. INCREASED FLASH FLOOD RISK 10-YEAR – HEC-RAS



WALLOW FIRE FIGURE 24. INCREASED FLASH FLOOD RISK 10-YEAR