HORSESHOE 2 FIRE

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Post-Burn Increased Flash Flood Risk Analysis

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NASA image of the Horseshoe 2 Fire taken from the International Space Station

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 Horseshoe 2 Fire are expected to see 5-year peak flows that range from 900 cfs to 5,600 cfs. These post-burn 5-year peak flows are 3 to 45 times greater than pre-burn peak flows. For this comparison the 5-year 30-minute pre-burn peak flows calculated by the interagency Horseshoe 2 BAER Team were used. The storm duration for the NWS post-burn peak flows is equal to the time of concentration for each basin evaluated. For these basins, the time of concentration ranged from 35 minutes to 140 minutes.

INTRODUCTION

This report is an assessment of the impact on the future hydrologic response of basins burned by the 2011 Horseshoe 2 Fire in Cochise County, Arizona. 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 5-year post-burn peak flows and the associated increased flash flood risks. The basins selected for analysis are a subset of those defined by the interagency Horseshoe 2 Fire BAER Team.

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. 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.

For the Horseshoe 2 Fire, an analysis of 28 watersheds using the Reed-Schaffner Equations 9 & 12 was performed. Equation 9 is a best-fit curve for smaller basins. Equation 12 is an envelope curve for small and larger basins. The post-burn flows were calculated for the 5-year storm with duration equal to or greater than the watershed's time of concentration (ranged from 35 to 140 minutes). The data used in these calculations were provided by the interagency Horseshoe 2 BAER Team. The time of concentrations, channel slope, and pre-burn 5-year flows, used in this study were previously calculated by the BAER Team.

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) elevation change less than 1500 feet, 3) no hyper-effective hydro soil group D, and/or 4) no hyper-effective hydro soil group C unless hydro soil group D coverage was significant.

The modified channel relief ratio was calculated by the USGS for 4 watersheds. The modified channel relief ratio was estimated for an additional 8 watersheds by Reed. For the remaining 16 of 28 watersheds the channel slope was used unmodified. This was done for basins with maximum elevations less than 8000 feet and those few where the estimated modified channel slope provided unreasonable results.

For basins greater than 20 square miles, the pre-burn 5-year runoff prorated to reflect runoff from the unburned portion of the basin was added to the results of equation 9. Since equation 12 only calculates runoff from the hyper-effective drainage area, the pre-burn 5-year runoff from the unburned portion of the basin was added to the results of equation 12. Final results reflect the 5-year post-burn runoff from the entire basin. Selected basin data are presented in Figure 1. Study results including the calculated post-burn peak flows are presented in Figure 2. Relative increase in flash flood risk is provided in Figures 3, 4, and 5.

FINDINGS

PEAK FLOWS: As expected the results of equation 12 are higher than equation 9. Therefore it is recommended that the results of equation 12 be used for analysis. The 28 basins selected for analysis are a subset of those defined by the interagency Horseshoe 2 Fire BAER Team. These basins impacted by the Horseshoe 2 Fire are likely to experience 5-year peak flows that range from 900 cfs to 5,600 cfs (Figure 2). These post-burn 5-year peak flows are 3 to 45 times greater than pre-burn peak flows (Figure 2). For this comparison the 5-year 30-minute pre-burn peak flows calculated by the interagency BAER Team were used. The storm duration for the post-burn peak flows is equal to the time of concentration for each basin evaluated. For these basins, the time of concentration ranged from 35 minutes to 140 minutes (Figure 2).

INCREASED FLASH FLOOD RISK: To evaluate the relative increase in flash flood risk, the 28 basins were ranked by post-burn basin yield (Figure 3). This relative increase in flash flood risk is shown spatially in Figures 4 and 5.

CONCLUSIONS

Storms with time of concentrations from 35 to 140 minutes over the burn area will cause significant increase in peak flows from impacted basins during the burn recovery period. Essentially, the shorter duration storms will impact the smaller basins near the hydrologic divide of the Chiricahua Mountains, and the larger duration storms will impact the larger basins at the mouth of the canyons in the vicinity of developments. The basins with relative increased flash flood risk have been indentified and are shown on Figures 3, 4, and 5. Four basins of particular interests are:

- **West Whitetail - Faraway Ranch**
- **West Whitetail - Visitors Center**
- **East Turkey - Paradise**
- **Cave - Portal**

These four basins were selected due to the potentially high impacts with elevated post-burn flows. This is true 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 time of concentration. For theses four basins post-burn flow results are:

West Whitetail - Faraway Ranch (NWS / 5-year 1-hour)
Relative Increased Flash Flood Risk: High
Post-Burn Flow (Eq. 9): 2,880 cfs
Post-Burn Flow (Eq. 12): 4,130 cfs
Precipitation: 1.79 inches

West Whitetail - Visitor Center (NWS / 5-year 1-hour)
Relative Increased Flash Flood Risk: High
Post-Burn Flow (Eq. 9): 2,050 cfs
Post-Burn Flow (Eq. 12): 2,890 cfs
Precipitation: 1.77 inches

East Turkey - Paradise (NWS / 5-year 1-hour)
Relative Increased Flash Flood Risk: High
Post-Burn Flow (Eq. 9): 2,380 cfs
Post-Burn Flow (Eq. 12): 2,990 cfs
Precipitation: 1.88 inches

Cave - Portal (NWS / 5-year 2-hour)
Relative Increased Flash Flood Risk: Moderate
Post-Burn Flow (Eq. 9): 2,200 cfs
Post-Burn Flow (Eq. 12): 2,460 cfs
Precipitation: 1.98 inches

REFERENCES

Reed, W. and M. Schaffner, 2008. Effects of Wildfire in the Mountainous Terrain of Southeast Arizona: Empirical Formula to Estimate 1-Year through 10-Year Peak Discharge from Post-Burn Watersheds. NOAA Technical Memorandum NWS WR-283.

Reed, W. and M. Schaffner, 2007. Effects of Wildfire in the Mountainous Terrain of Southeast Arizona: An Empirical Formula to Estimate 5-Year Peak Discharge from Small Post-Burn Watersheds. NOAA Technical Memorandum NWS WR-279.

ACKNOWLEDGEMENTS

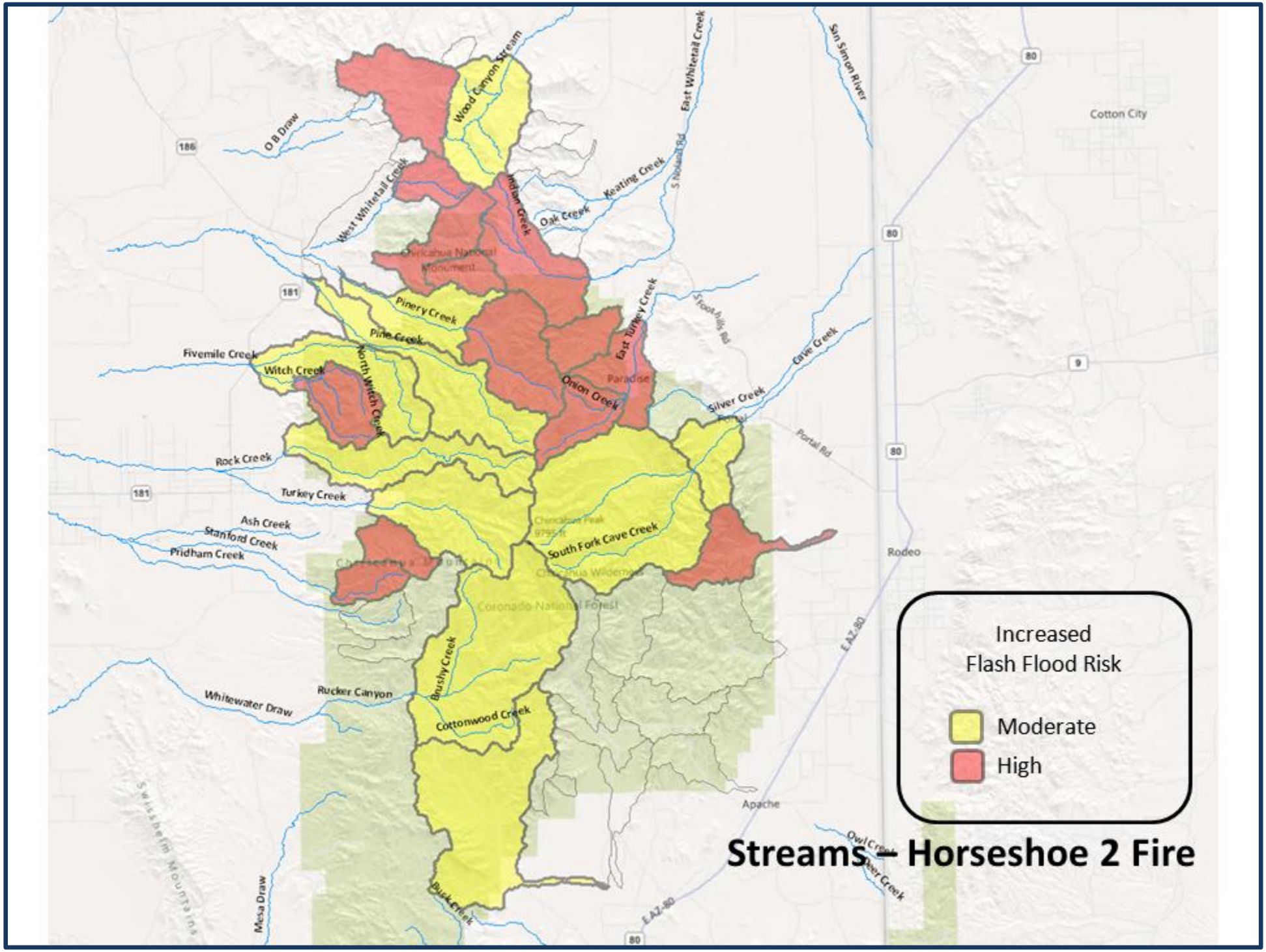
Many thanks to the interagency Horseshoe 2 Fire BAER Team for providing the necessary data on the burned basins to complete this analysis, and to the AZ USGS for providing channel relief information.

Horseshoe 2 Fire Figure 1. Selected Basin Values						
Basin	Drainage Area (sq. mi.)	**Hyper-Effective Drainage Area (sq. mi.)**	Maximum Elevation (ft.)	**Mean Basin Elevation (ft./1000)**	**Slope**	**Modified Channel Relief Ratio**
Ash at Cottonwood	4.4	**0.9**	8179	**6.81**		**0.0639**
Ash at Stanford	4.0	**2.2**	8046	**6.76**		**0.0626**
Cave at Portal	42.4	**9.4**	9750	**7.26**		**0.0600**
Cave at Sunny Flat Camp	26.4	**9.1**	9750	**7.42**		**0.0719**
East Turkey at Fireline	9.2	**4.7**	8017	**6.50**	**0.0669**	
East Turkey at Paradise	6.2	**2.9**	8504	**7.01**		**0.0900**
East Whitetail at Fireline	12.9	**8.1**	8086	**6.54**	**0.0792**	
East Whitetail at Juhs Fireline	4.9	**2.6**	8014	**6.59**		**0.0777**
Emigrant at Fireline	8.7	**4.9**	7325	**6.00**	**0.0916**	
Fivemile at Fife Canyon	8.7	**5.9**	7259	**6.21**	**0.0481**	
Fivemile at Hwy 181	16.7	**9.9**	7290	**6.12**	**0.0414**	
Fivemile at Witch Creek	7.2	**3.7**	7061	**6.09**	**0.0710**	
Pine at Hwy 181	14.2	**9.3**	9121	**7.07**		**0.0403**
Rock at Fireline	14.6	**4.7**	9659	**7.37**	**0.0696**	
Rucker at Fireline	15.6	**4.6**	9749	**7.79**		**0.0566**
Rucker at Camp Rucker	32.0	**9.7**	9742	**7.64**		**0.0482**
Sulphur at HUC6	7.3	**3.7**	8561	**6.36**		**0.0720**
Tex at Fireline	18.9	**6.4**	7689	**6.92**	**0.0404**	
Tex a HUC6	29.2	**7.1**	7980	**6.38**	**0.0445**	
Upper Pinery at Fireline	20.9	**13.4**	8799	**7.35**	**0.0536**	
Upper Pinery at Grave Stone	13.3	**9.3**	8563	**7.47**	**0.0653**	
Upper Pinery at Hwy 181	23.1	**13.6**	8804	**6.93**	**0.0556**	
Upper Turkey Creek at Fireline	18.2	**6.4**	9750	**7.63**		**0.0736**
West Whitetail at Fireline	4.3	**1.8**	7806	**6.60**	**0.1055**	
West Whitetail at Bonita Canyon Camp	4.2	**2.8**	7638	**6.80**	**0.0652**	
West Whitetail at Faraway Ranch	10.5	**5.4**	7800	**6.50**	**0.0799**	
West Whitetail at Visitor Center	3.7	**1.8**	7285	**6.32**	**0.0895**	
Wood at HUC 6	13.9	**4.6**	8102	**6.30**		**0.0620**

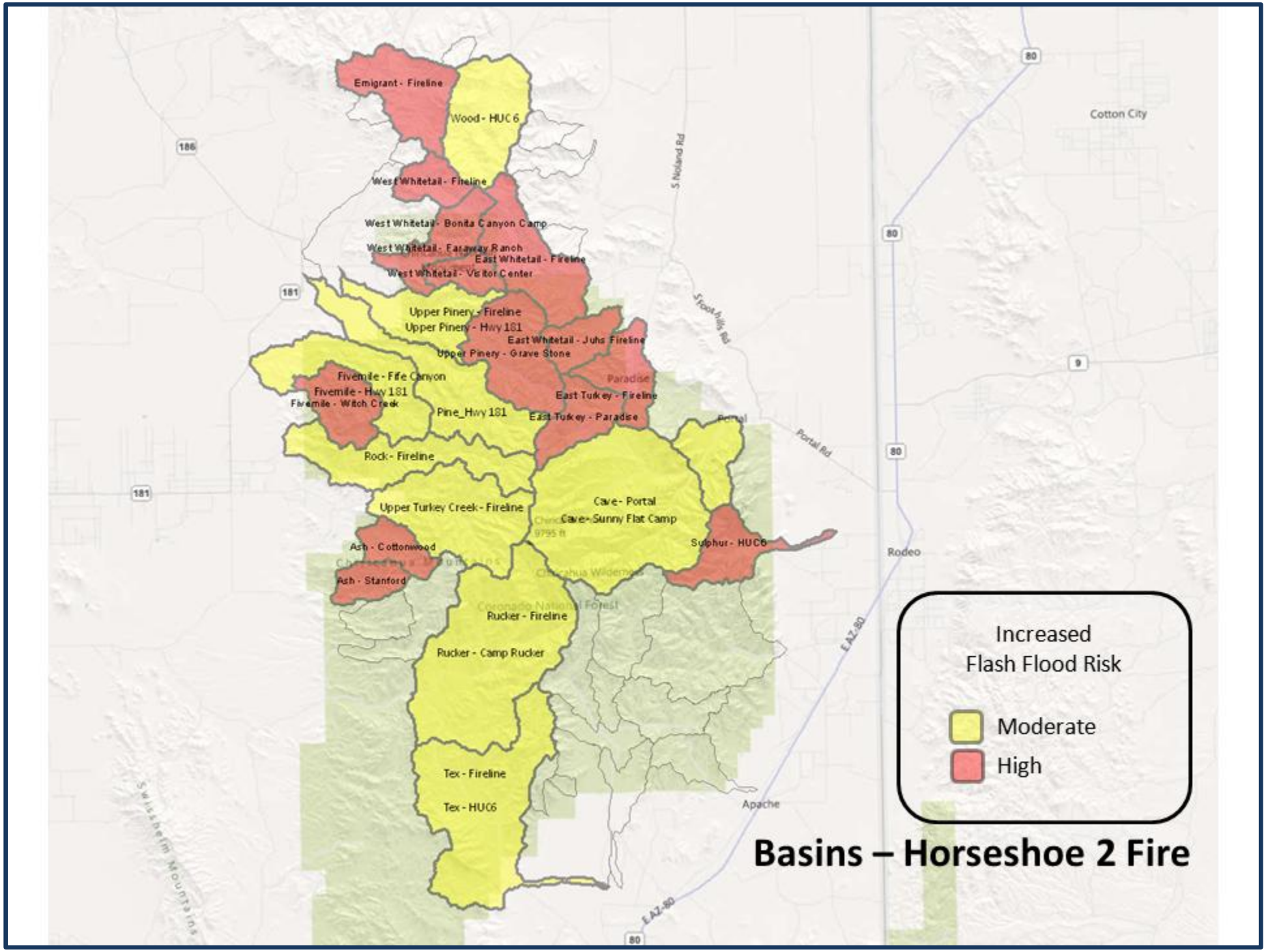
Note: modifies channel slope for Cave at Portal and East Turkey at Paradise provided by USGS.

Horseshoe 2 Fire Figure 2. Results					
Basin	**Equation 12 5-Year Post-Burn Peak (cfs)**	Equation 9 5-Year Post-Burn Peak (cfs)	**Storm Duration (minutes)**	**Post-Burn/Pre-Burn Ratio (cfs / cfs)**	**Post-Burn Basin Yield (cfs / sq. mi.)**
Ash at Cottonwood	**888**	644	**40**	**9**	**203**
Ash at Stanford	**1289**	1035	**37**	**45**	**325**
Cave at Portal	**2459**	2195	**102**	**7**	**58**
Cave at Sunny Flat Camp	**3499**	3203	**75**	**4**	**133**
East Turkey at Fireline	**2606**	1865	**84**	**5**	**284**
East Turkey at Paradise	**2991**	2376	**48**	**8**	**485**
East Whitetail at Fireline	**4515**	3491	**70**	**7**	**351**
East Whitetail at Juhs Fireline	**2579**	1825	**35**	**4**	**530**
Emigrant at Fireline	**5562**	3986	**53**	**8**	**639**
Fivemile at Fife Canyon	**1553**	1162	**92**	**14**	**178**
Fivemile at Hwy 181	**1636**	1162	**119**	**6**	**98**
Fivemile at Witch Creek	**2773**	2020	**55**	**11**	**383**
Pine at Hwy 181	**1068**	903	**125**	**20**	**46**
Rock at Fireline	**2102**	1725	**110**	**10**	**144**
Rucker at Fireline	**1216**	1047	**80**	**13**	**78**
Rucker at Camp Rucker	**1576**	1451	**105**	**4**	**49**
Sulphur at HUC6	**2540**	1959	**70**	**23**	**350**
Tex at Fireline	**1176**	1015	**88**	**3**	**62**
Tex a HUC6	**1735**	1436	**140**	**3**	**59**
Upper Pinery at Fireline	**2224**	1997	**104**	**4**	**106**
Upper Pinery at Grave Stone	**2571**	2161	**67**	**4**	**194**
Upper Pinery at Hwy 181	**2685**	2313	**122**	**6**	**116**
Upper Turkey Creek at Fireline	**2569**	2172	**65**	**9**	**142**
West Whitetail at Fireline	**3485**	2715	**42**	**15**	**811**
West Whitetail at Bonita Canyon Camp	**1736**	1272	**55**	**3**	**409**
West Whitetail at Faraway Ranch	**4129**	2873	**61**	**4**	**394**
West Whitetail at Visitor Center	**2892**	2050	**42**	**6**	**782**
Wood at HUC 6	**2419**	1661	**64**	**6**	**174**

Horseshoe 2 Fire Figure 3. Increased Flash Flood Risk		
Basin	**Post-Burn Basin Yield (cfs / sq. mi.)**	**Relative Increased Risk**
West Whitetail at Fireline	811	High
West Whitetail at Visitor Center	782	High
Emigrant at Fireline	639	High
East Whitetail at Juhs Fireline	530	High
East Turkey at Paradise	485	High
West Whitetail at Bonita Canyon Camp	409	High
West Whitetail at Faraway Ranch	394	High
Fivemile at Witch Creek	383	High
East Whitetail at Fireline	351	High
Sulphur at HUC6	350	High
Ash at Stanford	325	High
East Turkey at Fireline	284	High
Ash at Cottonwood	203	High
Upper Pinery at Grave Stone	194	High
Fivemile at Fife Canyon	178	Moderate
Wood at HUC 6	174	Moderate
Rock at Fireline	144	Moderate
Upper Turkey Creek at Fireline	142	Moderate
Cave at Sunny Flat Camp	133	Moderate
Upper Pinery at Hwy 181	116	Moderate
Upper Pinery at Fireline	106	Moderate
Fivemile at Hwy 181	98	Moderate
Rucker at Fireline	78	Moderate
Tex at Fireline	62	Moderate
Tex at HUC6	59	Moderate
Cave at Portal	58	Moderate
Rucker at Camp Rucker	49	Moderate
Pine at Hwy 181	46	Moderate



Horseshoe 2 Fire Figure 4. Increased Flash Flood Risk showing Creek and Canyon Names



Horseshoe 2 Fire Figure 5. Increased Flash Flood Risk showing BAER Team Basin Names