Geodatabase of Post-Wildfire Study Basins

Assessing the predictive strengths of post-wildfire debris-flow models in Arizona and defining rainfall intensity-duration thresholds for initiation of post-fire debris flow

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Geodatabase of Post-Wildfire Study Basins

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Introduction

Wildfires are increasing in size and severity across the western U.S. (Stephens, 2005; Littell and others, 2009). Concurrently, encroachment and development into the wildland-urban interface (WUI) is increasing, placing people at greater risks from wildfires and from the aftermath of fires (Stein and others, 2013). The Arizona Geological Survey (AZGS) is using data from recent wildfires and debris flows in Arizona, in cooperation with the U.S. Geological Survey (USGS), to assess how well available USGS models predict post-wildfire debris flows and to define rainfall intensity-duration thresholds that trigger post-fire debris flows.

DI-44 version 1.0 contains the data collected and developed during the initial phase of this work. A short description of the project is provided below; a full description is in Appendix B of Youberg (2014). Included in this report are the geospatial data from the study: study basins and outlet locations, wildfire perimeters and final soil burn severity data, rain gauge locations, and 10 m digital elevation models with associated hill shaded models. Data from new wildfires will be added as they become available.

The purpose of this project is two-fold. The first is to assess the predictive strengths of USGS post-wildfire debris-flow probability models and a post-fire debris-flow volume model for use in Arizona. These models are used during Burned Area Emergency Response (BAER) team assessment to identify areas of concern in national forests, and may be of use in making preliminary hazard assessments for other areas affected by wildfires. The second is to objectively define rainfall intensity-duration (ID) thresholds above which post-fire debris-flow are likely to occur. These thresholds provide guidance as to when to issue warnings as storms approaches or develops over burned areas. A geodatabase was built to house geospatial data of the recently burned basins, associated precipitation data from gauges within or adjacent to the burned area, and basin flow responses (no response/floods/debris flows) resulting from the rainfall.

Methods

During the first summer following a major fire, study basins were established for the purpose of monitoring and documenting basin response following significant rainfall. Typically, study basins are identified as having moderate to high potential for post-fire debris flow occurrence due to burn severity and watershed characteristics. When flows occur, field assessments of deposits are used to determine the occurrence, or not, of debris flows. Basins are defined by the downstream extent of debris flows and, where possible, intact deposits are mapped to estimate debris-flow volumes. Basins outlets are located 1) at a break in channel slope or a substantial decrease in channel confinement, often delineated by a fan or debris-flow deposit, 2) by a channel junction, or 3) by a value-at-risk (e.g. a bridge or a culvert). Basin flow response data is binary; for each basin and storm, the flow response is classified as either a debris flow (1) or not a debris flow (0), which includes floods, hyperconcentrated flows and no flow responses.

Several factors limit field observations, and these, in turn affect the accuracy of the data and propagate throughout the work. Identifying and discriminating debris-flow deposits from flood deposits may be challenging due to reworking by subsequent floods (Melis and others, 1997, type III flows). Debris flows and floods are part of a continuum of fluid-sediment

flows, thus in some cases it is difficult to confidently assess whether deposits were emplaced by floods or debris flows (Pierson, 2005). Field observations sometimes occur after road crews have removed all material so deposits cannot be assessed. And finally, limited exposures of deposits make it difficult to assess sorting, bedding, and other important deposit characteristics. In all cases when it was not possible to verify that a debris flow has occurred or that the deposit is debris-flow related, the basin flow is classified as non-debris-flow.

Raw precipitation data is collected from rain gauges within or adjacent to the fire perimeters. These data yield information on rainfall intensity-duration thresholds. Monsoonal rainfall in Arizona is characterized by short-duration, convective thunderstorms, and several storms can occur within a 24-hour period. Here, storms are separated based on a minimum 3-hour period of no rain (Restrepo-Posada and Eagleson 1982).

Rainfall storm totals (mm) and average storm intensities (mm/hr) are calculated for each storm. Rainfall ID thresholds are developed from all of the rainfall data first by calculating peak rainfall intensity for durations of 5, 10, 15, 30, and 60 minutes (I5-I60) for each storm that occurred during the first summer. These duration intervals are selected because most of the storms analyzed to date have durations of an hour or less, with only a few storms lasting longer than two hours. To calculate the peak intensities of interest, an intensity for every minute of each storm is calculated by backwards differencing cumulative rainfall for the various durations using the following equation:

$$I_D(t) = ((R(t)-R(t-D)))/D$$

Where, I_D is rainfall intensity (mm/hr), t is time, R is the cumulative rainfall (mm), and D is the duration (hours) (Staley et al. 2013). Storm data from each rain gauge is then classified with a binary parameter to define storms that produced at least debris flow (1) or no debris flows (0, sediment-laden floods or no responses). Because monsoonal storms are typically limited in areal extent, rainfall amounts can vary dramatically across the burned area. This means that for any given storm, data from one rain gauge may be classified as a debris-flow producing storm while data from another gauge on a different part of the same burn scar is classified as a non-debris-flow producing storm. Where possible, Level III NEXRAD radar data was used to determine which basins received rainfall representative of the nearest gauge.

Wildfires in DI-44 Version 1.0

Data from six recent and two older wildfires are included in version 1.0 of the database (Figure 1). Data was collected from the 2014 Slide, 2012 Gladiator, 2011 Monument, 2011 Horseshoe 2, 2011 Wallow and 2010 Schultz Fires following the methodology outlined above. The 2014 Slide Fire was not included in the original study by Youberg (2014) but is included here as data from the first monsoon following the fire has been collected and analyzed. Rainfall and basin response data from the six recent wildfires were collected from a total of 92 basins and 12 rain gauges that recorded rainfall information from 105 storms (Appendix A), 12 of which produced debris flows. Fifty-six of the 92 basins were located within 2 km of a rain gauge and were used to develop objectively defined rainfall intensity-duration threshold curves.

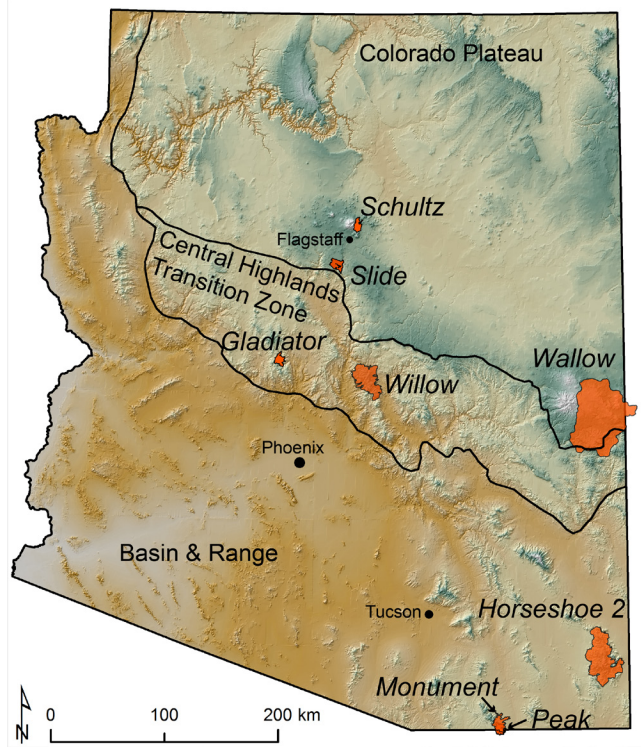

Figure 1. Physiographic provinces of Arizona and locations of study wildfires.

The two older wildfires are the 2004 Willow and 1988 Peak Fires. These fires were not monitored for basin responses throughout the summer, rather data were collected in one or two field visits to document the occurrence of debris flows within the burned basins in response to one storm. There is no associated rainfall for these two wildfires.

Schultz Fire, 2010, San Francisco Peaks, Flagstaff, Arizona

The Schultz Fire burned 6,100 hectares (ha) of the eastern slopes of the San Francisco Peaks northeast of Flagstaff between June 20th and 30th, 2010 (Figure 1; USDA Forest Service, 2010). The San Francisco Peaks are a Pleistocene composite volcano with complex interbedded volcanic rocks overlain by glacial, colluvial and alluvial surficial deposits (Holm, 1988). The fire burned through forests of ponderosa pine and mixed conifer across slopes of 30% to over 100%, consuming the majority of the burned area during the first 24 hours (USDA Forest Service, 2010). The soil burn severity map shows more than half of the area burned at moderate (27%) and high (40%) severity (Figure 2A, Table 1). Elevations within the burned area range from approximately 2,100 m at the forest boundary to 3,370 m near Doyle Peak at the top of the burned area.

Three, 1-mm tipping-bucket automated local evaluation in real-time (ALERT) rain gauges (3450, 3460 and 3470) were installed within the burned area below the steep, upper slopes after the fire but prior to first rainfall. Thirty-one basins were monitored to document basin flow responses from rainfall (Figure 2A, Table 2). Ten of these basins were inset into larger basins. Both the smaller inset basins and the larger basins were delineated based on the presence of debris flows deposits. Twenty-four of the monitored basins had at least one debris flow (Table 2). Nineteen of the monitored basins were within 2 km of a rain gauge and were used to develop objectively-defined rainfall intensity-duration threshold curves.

Horseshoe 2 Fire, 2011, Chiricahua Mountains, southeastern Arizona

The Horseshoe 2 Fire burned 90,226 ha of the Chiricahua Mountains in southeastern Arizona between May 8th and June 25th, 2011 (Figure 1; USDA Forest Service, 2011a). The fire burned approximately 70% of the mountain range and currently stands as the 4th largest wildfire in state history. The soil burn severity map shows 30% of the Horseshoe 2 Fire burned at moderate severity and 12% at high severity (Figure 2B, Table 1; Youberg, 2011). The fire burned between elevations of approximately 1,300 m near the base of the range to 2,975 m at Chiricahua Peak consuming grasslands, Madrean woodlands and forest composed of oak, piñon-juniper, and pine and conifers forests (Arizona Firescape, http://www.azfirescape.org). Geologic units include a diverse suite of Proterozoic, Paleozoic, and Cretaceous metamorphic, sedimentary and volcanic rocks, Oligocene volcanic rocks, and Quaternary basalts and surficial deposits (Pallister and du Bray, 1992, 1994; Drewes, 1996).

One research rain gauge (time-stamped 2 mm tipping bucket) was installed in the East Turkey Creek drainage just below Buena Vista Peak, north of Rustler Park, on July 1, 2011 (Figure 2B, Chiri2). A temporary National Weather Service weather station was installed on the drainage divide between East Turkey Creek and Pine Canyon, south of Rustler Park, on July 26, 2011 (Figure 2B, KC2CPZ1). The weather station recorded timestamped packets of data with variable time intervals and rainfall amounts.

Twenty-five basins in Pinery, Pine and East Turkey Creek Canyons were monitored to assess the post-wildfire basin responses (Figure 2B, Table 2). Ten of the monitored basins were inset into larger basins. Both the smaller inset basins and the larger basins were delineated based on the presence of debris flows deposits. Fifteen of the monitored basins had at least one debris flow (Table 2). Ten of the monitored basins were within 2 km of a rain gauge and were used to develop objectively defined rainfall intensity-duration threshold curves.

Wallow Fire, 2011, east-central Arizona and western New Mexico

The Wallow Fire burned 217,740 ha in the White Mountains of east-central Arizona and western New Mexico from May 29th to July 8th, 2011 (Figure 1; USDA Forest Service, 2011c), and currently stands as the largest wildfire in state history. The soil burn severity map shows 14% of the area burned at

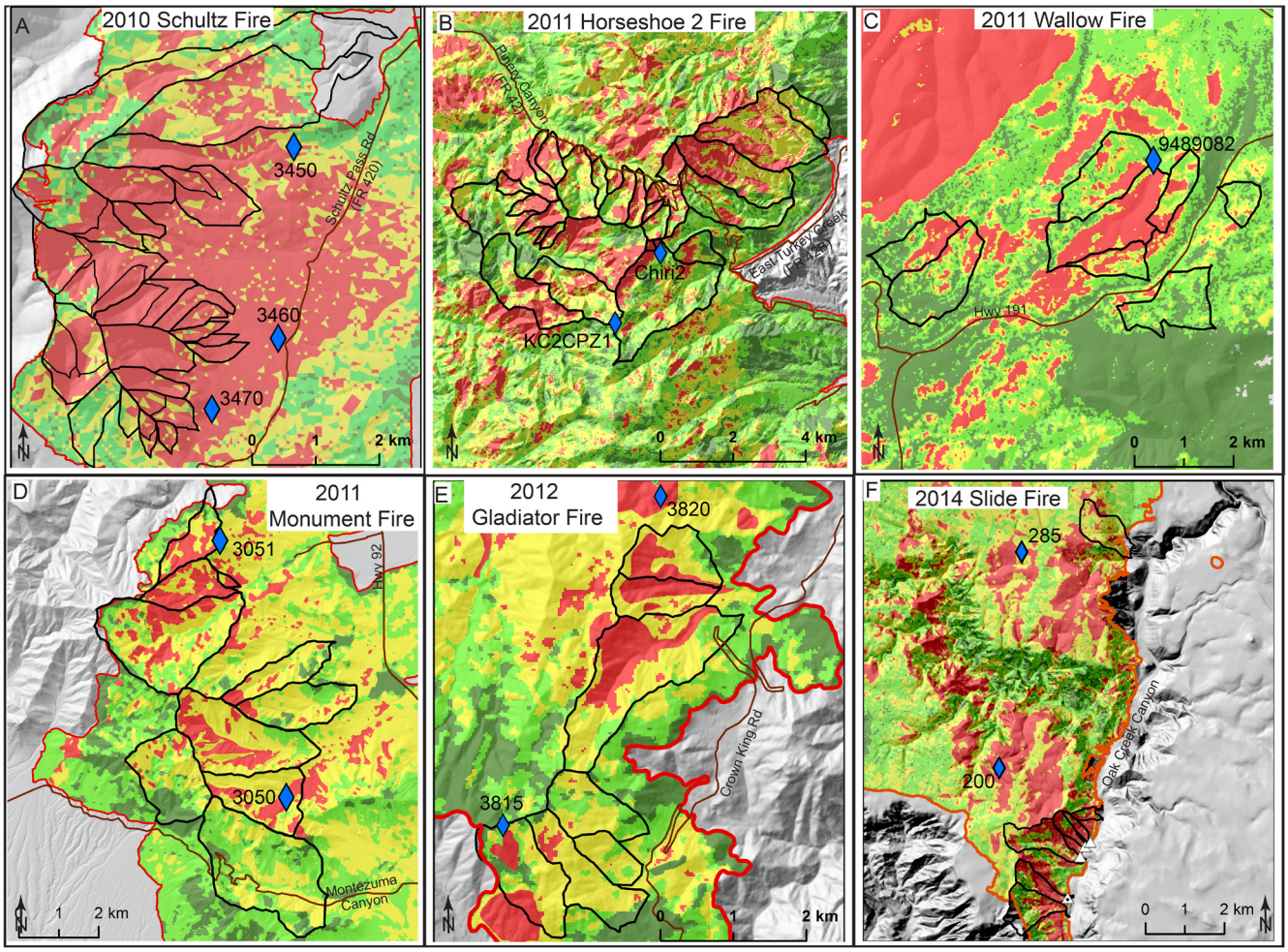

Figure 2. Locations of study basins. Panel A: 2010 Schultz Fire, Panel B: 2011 Horseshoe 2 Fire, Panel C: 2011 Wallow Fire. Panel D: 2011 Monument Fire, Panel E: 2012 Gladiator Fire, Panel F: 2014 Slide Fire. Study basins outlined in black. Rain gauge locations shown with blue diamonds. Fire perimeters outlined in red. Soil burn severity shown by colors of dark green (unburned), light green (low soil burn severity), yellow (moderate) and high (red).

moderate severity and 17% at high severity (Figure 2C, Table 1; USDA Forest Service, 2011c). Vegetation consumed by the fire includes mountain grasslands, piñon-juniper, ponderosa pine, mixed conifer, spruce-fir and riparian vegetation between elevations of approximately 1,570 m to 3,325 m across a diverse group of rocks with dominant lithologies of mid- and late-Cenozoic sedimentary and volcanic rocks (Richard and others, 2000).

A continually operating USGS rain gauge (9489082, 15-minuted binned data) is located at the weir on the North Fork of Thomas Creek, one of the research basins (Figure 2C). Three of the monitored basins had at least one debris flow (Table 2).Eight basins were monitored for basin responses (Figure 2C, Table 2). Four of the basins had been part of a USDA Rocky Mountain Research Station long-term watershed study from 1962-1984 (Heede, 1985), and were re-instrumented immediately following the fire to monitor post-wildfire runoff and erosion (Wagenbrenner and Robichaud, 2013). The other four basins are adjacent to the research basins. The four research basins and a fifth adjacent basin were within 2 km of the rain gauge and were used to develop objectively defined rainfall intensity-duration threshold curves.

Monument Fire, 2011, Huachuca Mountains, southeastern Arizona

The human-caused Monument Fire burned 12,353 ha in the Huachuca Mountains in southeastern Arizona between June 12th and July 8th, 2011 (Figure 1; USDA Forest Service, 2011b). Almost half of the fire area burned at moderate (39%) and high (7%)

soil burn severity, mostly on the steeper mountain slopes (Figure 2D, Table 1; USDA Forest Service, 2011b). The fire burned between the elevations of 1,335 m and 2,885 m across grasslands and Madrean oak, piñon-juniper, pine and conifers woodlands and forests (Arizona Firescape, http://www.azfirescape.org). Lithologies include Precambrian granite on the lower flanks of the mountain, and numerous Paleozoic sedimentary units, Mesozoic volcanic and sedimentary rocks, and Quaternary surficial deposits (Hayes and Raup, 1968).

Two 1-mm tipping-bucket ALERT rain gauges were installed within the burned area during the first week of July, prior to full containment. One gauge was installed at the north end of the fire on the ridge between Carr and Miller Canyons (3051), and the other gauge was installed at the south end of the fire on the lower slopes of upper Ash Canyon (3050). Ten basins were monitored to assess the post-wildfire debris-flow models (Figure 2D). Five of the monitored basins had at least one debris flow (Table 2). Five of the monitored basins were within 2 km of a rain gauge and were used to develop objectively defined rainfall intensity-duration threshold curves.

Gladiator Fire, 2012, Bradshaw Mountains, central Arizona

The Gladiator Fire burned 6,560 ha near Crown King in the Bradshaw Mountains of central Arizona between May 13th and June 13th, 2012 (Figure 1; USDA Forest Service, 2012). The fire burned across Chaparral, Ponderosa Pine and lesser amounts of mixed conifer forests between the elevations of 1,241 m and 2,316 m. Half of the area was burned at moderate (32%) and high (21%) soil burn severity (Figure 2E, Table 1; USDA Forest Service, 2012). Geologic units within the burned area include Precambrian granite, volcanic and metamorphic rocks (Anderson and Blacet, 1972).

After the fire three tipping-bucket ALERT gauges were installed within the burned area, two of which are located adjacent to seven monitored basins on the eastern perimeter of the fire along Crown King Road (Figure 2E). One gauge was located near Peck Mine (3830) at the north end of the study basins and one was located on Lincoln Ridge (3815) at the south end of the study basins. Three of the monitored basins had at least one debris flow (Table 2). All seven basins were

Table 1. Fire location and dates, area burned, and final soil burn severity as a percentage of the entire burned area, and number of basins monitored.

Fire Name	Range	Dates Burned	Total Area Burned[1] (ha)	Soil Burn Severity (% of Total Area)			
				Unburned	Low	Moderate	High
Schultz	San Francisco Peaks	6/20-30 2010	6,100	8	25	27	40
Horseshoe 2	Chiricahua Mountains	5/8-7/20 2011	90,226	20	38	30	12
Wallow	White Mountains	5/29-7/8 2011	217,740	22	47	14	17
Monument	Huachuca Mountains	6/12-7/12 2011	12,353	14	40	39	7
Gladiator	Bradshaw Mountains	5/13-6/13 2012	6,572	18	29	32	21
Slide	Mogollon Rim	5/20-6/4 2014	8,860	6	48	32	14
Willow	Mazatzal Mountains	6/24-7/17 2004	48,359	3	11	56	30
Peak	Huachuca Mountains	6/10-NA[2], 1988	6,500	2	20	61	17

[1]Area burned and burn severity data from final soil burn severity images (tiffs or rasters).
[2]Not available.

Table 2. Monitored basins and basin responses.

Wildfire Name	Number of		Basin Size (km^2) Range (Ave)	Number of:	
	Monitored Basins	Inset Basins		Flood Basins	Debris-Flow Basins
Schultz Fire	31	10	0.1-3.6 (0.7)	7	24
Horseshoe 2 Fire	25	10	0.1-13.5 (1.8)	10	15
Wallow Fire	8	0	0.5-2.3 (1.4)	5	3
Monument Fire	10	0	0.1-5.9 (3.0)	5	5
Gladiator Fire	7	0	0.4-2.4 (1.0)	4	3
Slide	7	0	0.2-1.1 (0.6)	7	0

within 2 km of a rain gauge and were used to develop objectively defined rainfall intensity-duration threshold curves.

Slide Fire, 2014, Oak Creek Canyon, Sedona, AZ

The Slide Fire burned 8,860 ha north of Sedona in Oak Creek Canyon and along the Mogollon Rim between May 20th and June 4th, 2014 (Figure 1; USDA Forest Service, 2014). The fire burned between elevations of 1,525 m to 2,225 m through riparian corridors, chaparral, gambel oak, ponderosa pine and, at the highest elevations, mixed conifer. Almost half of the area burned at moderate (32%) and high (14%) soil burn severity (Figure 2F, Table 1; Steinke and MacDonald, 2014). Geologic units within the burned area includes Pliocene to Miocene basalts, Paleozoic sedimentary rocks and Quaternary alluvium and colluvium (Haessig, 2014). Three ALERT rain gauges were installed within the burn area, two along the Mogollon Rim at North East Pocket (200) at the south end of the study area and one at Harding Point (285) at the north end of the study basins (Figure 2F).

The Landslides Division of the United State Geological Survey USGS) conducted a preliminary hazard assessment for the burned area emergency response (BAER) team to identify the potential for post-fire debris flows in basins burned by the Slide Fire (http://landslides.usgs.gov/hazards/postfire_debrisflow/2014/20140520slide/). Eleven of these basins were selected for monitoring flow responses to rainfall due to the high potential hazard identified in the USGS preliminary hazard assessment, evidence of past debris flows, and accessibility (Figure 2F). At the southern end of the study area, hunting cameras were installed on the fans of three study basins to constrain the timing of flows, and a rain-triggered video camera was instrumented on a fourth study basin. The video camera is triggered by an Onset tipping-bucket rain gauge when precipitation exceeds a predetermined threshold. A second Onset gauge was also installed on one of the study fans instrumented with hunting cameras. Data from these two gauges provide a basis for comparison of rainfall at the bottom of the basins with rainfall at the top as captured by the North East Pocket ALERT gauge. None of the monitored basins, however, had debris flows during the 2014 monsoon (Table 2). Ten of the monitored basins were within 2 km of a rain gauge and were used to develop objectively defined rainfall intensity-duration threshold curves.

Willow Fire, 2004, Mazatzal Mountains, central Arizona

The Willow Fire burned 48,359 ha in the Mazatzal Mountains of central Arizona between June 24 and July 17, 2004 (Table 1; http://gacc.nifc.gov/swcc/). The fire burned across Pinon-Juniper grasslands and chaparral, and mixed Ponderosa Pine forests. Data from the Willow Fire comes from mapping the

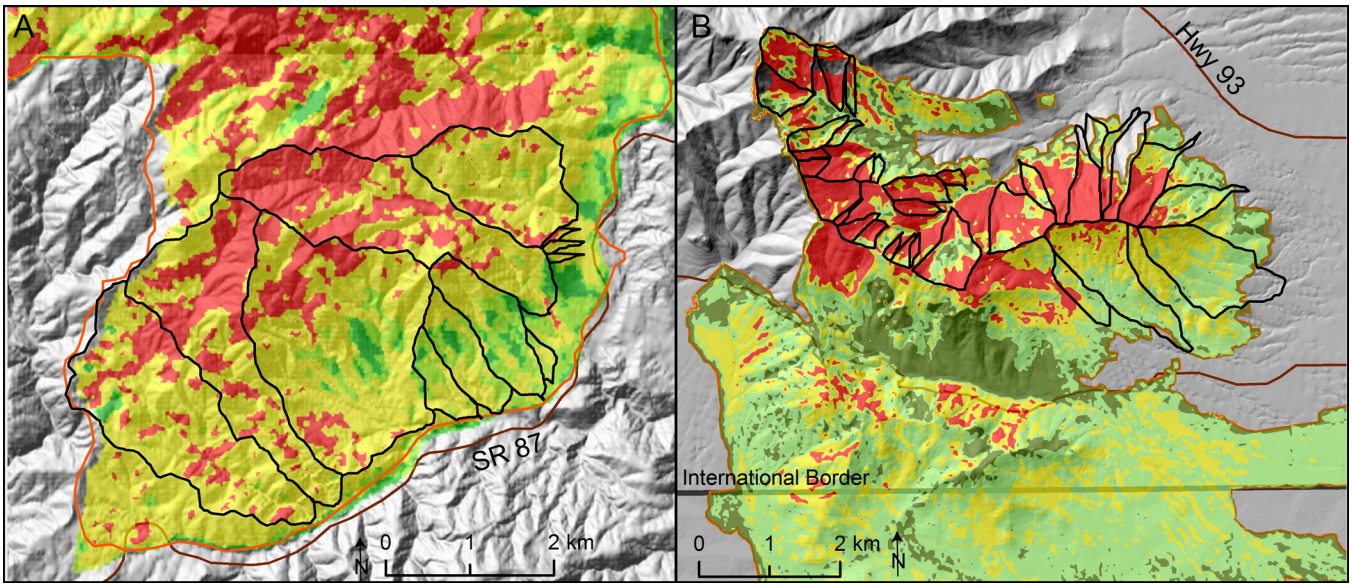

Figure 3. Locations of study basins. Panel A: 2004 Willow Fire, Panel B: 1988 Peak Fire. Study basins outlined in black. Rain gauge locations shown with blue diamonds. Fire perimeters outlined in red. Soil burn severity shown by colors of dark green (unburned), light green (low soil burn severity), yellow (moderate) and high (red).

burned basins along State Highway 87 (Pearthree and Youberg, 2004). Mapping was done to document basins that had at least one debris flow (Figure 3). This area was not monitored closely throughout the summer, so it is not certain when most of the individual debris flows occurred, and rainfall data was not collected.

Peak Fire, 1988, Huachuca Mountains, southeastern Arizona

The 1988 Peak Fire burned approximately 6500 ha in the Huachuca Mountains of southeastern Arizona (Monitoring Trends in Burn Severity, http://www.mtbs.gov/). Data from the Peak Fire comes from mapping by Wohl and Pearthree (1990; 1991). Mapping was done to document basins that had at least one debris flow (Figure 3), but basins were not monitored throughout the summer, so it is not certain when most of the individual debris flows occurred, and rainfall data was not collected.

Digital Information Product Overview, V 1.0

Geodatabase AZWildfires_DI44_v1.0 contains eight feature datasets, one single point feature class, and seven 10 m digital elevation models (DEMs) with associated hillshaded DEMs. In addition, an excel spreadsheet provides rainfall data and associated basin response from the 12 study rain gauges.

Single Point Feature Class – RainGages_AZFires

A point feature class with rain gauge names, IDs, and locations of gauges used to monitor basin responses in five wildfires; Schultz, Horseshoe 2, Wallow, Monument, Gladiator and Slide Fires. There are no rain gauge data for the Peak or Willow Fires.

Feature Datasets

There are eight feature datasets, one for each fire: 2012 Gladiator (Gld), 2011 Horseshoe 2 (H2F), 2011 Monument (Mon), 1988 Peak (Peak), 2010 Schultz (Sch), 2014 Slide (Sld), 2011 Wallow (Wal), and 2004 Willow (Wil). Each feature dataset contains four feature classes with the exception of the Slide feature dataset which includes an additional point feature class with locations of the cameras.

xxx_BsnOutlets – point feature class of the basin outlets. Data included in this feature class include basin response, date(s) of debris flows, volume estimates if available and associated rain gauges.

xxx_BsnPolys – polygon feature class of the basins. Data includes basin responses, date(s) of debris flows, and reporting or tracking and confidence

information. Confidence is the level of surety regarding whether or not a debris flow occurred, or regarding the date of the debris flow. Check comments.

xxx_FinalSoilBurnSeverity – polygon feature class of the final soil burn severity. 1 = unburned, 2 = low burn severity, 3 = moderate burn severity, 4 = high burn severity.

xxx_FirePerimeter – polygon feature class of the extent of the fire.

Raster Datasets

For each fire the geodatabase contains a 10 m DEM and associated hillshaded (Hs) DEM named for the mountain range in which the fire occurred. The 2011 Monument and 1988 Peak Fires both occurred the Huachuca Mountains.

Metadata

Metadata is in FGDC CSDGM format and provided for each feature dataset and feature data class.

Version History

Version 1.0: First version of the geodatabase. Contains seven wildfires: 2010 Schultz, 2011 Horseshoe 2, 2011 Wallow, 2011 Monument, 2012 Gladiator, 2014 Slide, 2004 Willow, and 1988 Peak.

Appendix A

Appendix A is an excel file containing rainfall intensity data from the 12 study gauges.

Acknowledgments

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