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August

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RE: Coconino County Post-Wildfire Flood and Debris Flow Risk Assessment, Task 4 - Pre-Fire Debris Flow Risk Assessment Summary

Aric Stewart:

This letter report describes Task 4, Pre-Fire Debris-Flow Risk Assessment, of the ongoing Coconino County Post-Wildfire Flood and Debris Flow Risk Assessment Pilot Project. The purpose of Task 4 is to evaluate the potential for debris flows in the unburned watersheds identified and selected in Tasks 1 and 2. During Task 1 we identified potential debris-flow corridors, which are generally confined to a specific flow path within a larger watershed, and during Task 2 we evaluated those corridors to select two watershed areas for the pilot study (Loverich and Kellogg, 2016). As discussed in a previous memorandum, dated June 29, 2016 (Loverich and Kellogg), the process of identifying areas prone to post-wildfire debris-flow and flood risk relied on a numerical ranking scheme, common sense, and geologic and engineering judgment to find watersheds that appear to be at risk. As part of our considerations, we included watersheds that perhaps didn't rank high numerically but appeared to exhibit characteristics similar to the east side of the San Francisco Peaks, where numerous debris flows and extensive flooding occurred after the 2010 Schultz Fire.

During Task 4, we conducted an assessment of the two pilot watersheds to identify tributaries with evidence of past debris flows. Evidence of past debris-flow activity indicates that there is a potential for future debris-flow activity. Basins that have had debris flows in the past are more likely to have debris flows in the future, given the right hydroclimatic and/or disturbance scenarios such as extensive, moderate to high severity burns. Results from this task will inform the modeling in Task 7.

This project is divided into 9 tasks. Tasks 1 and 2 were described in a previous memorandum dated June 29, 2016. This letter report describes Task 4.

*Task 1: County-Wide Assessment & Prioritization.*

*Task 2: Pilot Area Selection.*

*Task 3: Pre-Wildfire Hydrologic Modeling.*

***Task 4: Pre-Fire Debris Flow Risk Assessment.***

*Task 5: Burn Severity Scenario Modeling.*

*Task 6: Post-Wildfire Hydrologic Modeling.*

*Task 7: Post-Wildfire Debris Flow Risk Assessment.*

*Task 8: Risk Zone Mapping.*

*Task 9: Community Outreach.*

## **BACKGROUND**

Debris flows have been documented all across Arizona under a variety of conditions. In undisturbed (i.e. unburned) areas, debris flows may be initiated by slope failures due to unusually prolonged or intense precipitation falling onto saturated hillslopes (Cannon and Ellen, 1985; Webb and others, 2008; Montgomery and others, 2009). Unlike saturation-induced debris flows, post-wildfire debris flows can be initiated by runoff after fires under low antecedent soil moisture conditions (Kean and Staley, 2011; Kean and others, 2011; Schmidt and others, 2011). Wildfires dramatically alter watershed hydrologic conditions by reducing infiltration and increasing runoff, significantly increasing the probability and frequency of post-wildfire sediment-laden floods and debris flows (Wells, 1987; Meyer and Wells, 1997; Cannon, 2001; Neary and others, 2005; Ebel and others, 2012; Moody and others, 2013; Moody and others, 2016). Post-fire sediment-laden flood flows occur more frequently than debris flows, and may extend farther downstream and cover broader areas. Debris flows can be significantly more destructive than floods (Gartner and others, 2004), however, and can be intimately linked to sediment-laden floods. Some factors identified as influencing the occurrence of post-fire debris flows or floods include burn severity, geology, catchment size and gradient, and storm characteristics and movement through the basin (Wohl and Pearthree, 1991; Cannon and Gartner, 2005; Cannon and others, 2008). Post-fire erosion, leading to floods and debris flows, are also a function of the rainfall intensity (Moody and Martin, 2009; Cannon and others, 2011; Kean and others, 2011; Staley and others, 2013). Post-wildfire debris-flows tend to be generated by relatively common, low-magnitude, high-frequency storms (Cannon and others, 2008), and the timing and the magnitude of these debris flows are most strongly controlled by short-duration (< 30 min), high-intensity rainfall (Kean and others, 2011; Kean and others, 2012; Staley and others, 2013; Staley and others, 2015) that are typical of monsoon storms in Arizona.

Debris flows are unsteady, non-uniform, very poorly sorted sediment slurries (Costa and Williams, 1984; Iverson, 2003). Deposition occurs when debris flows become unconfined and/or where channel slopes decrease (Youberg, 2010). Unlike deposits left by sediment-laden flood flows, deposits left by debris flows do not exhibit sorting of grain sizes and often form positive relief, geomorphic features such as levees and snouts or terminal lobes (Costa, 1984; Pierson, 2005). Levees are long, linear deposits that form along the edges of channels as the flow front passes while snouts or terminal lobes are bulbous with steep fronts that form as flows lose momentum and stop, typically in unconfined areas such as

alluvial fans and meadows (Costa, 1984). Both levees and snouts are coarse-clast deposits, typically with an open framework, and often composed of very poorly sorted boulder- to cobble-sized clasts (Figure 1, Pierson, 2005).



Figure 1. Debris-flow deposits are typically unsorted, open framework, cobble- to boulder-sized clasts forming positive-relief geomorphic features. This linear feature is interpreted to be a debris-flow levee. (Photo: M. Kellogg)

## **RESULTS FROM TASK 4**

The primary focus of this task was to assess, in general terms, if the study watersheds could have debris flows after a disturbance such as wildfire. To do this, we conducted reconnaissance field investigations to ascertain if evidence of past debris flows is present in drainages of the two pilot study areas identified and selected in Tasks 1 and 2, Fort Valley and Williams. Field observations were made at various locations on three main drainages at the north end of Fort Valley (Figure 2), along the entire length of the channel between City Reservoir and the ski area on Bill Williams Mountain, two smaller drainages on High School Hill, and near the outlets of several other smaller drainages in Williams, as access permitted (Figure 3). We assessed conditions within and along channels, and in unconfined alluvial fan and meadow areas. We documented the presence, or absence, of boulder deposits and assessed the characteristics of the boulder deposits we did find.

### **Findings**

On all the main drainage channels we found boulder deposits that had levee- and snout-like forms, and are likely associated with past debris flows (Figures 4 and 5). Most of these deposits were located in the lower channel areas and on alluvial fans, while many were found within and adjacent to the channels higher in the basins. We also found debris-flow like boulder deposits on several, but not all, tributary drainages, typically at the confluence with the main drainage. Within Williams, some drainages were not

assessed near the outlets, where debris-flow deposits would most likely be expected to be present, because of accessibility issues. All boulder deposits that we observed and assessed as likely due to debris flows were located well within the boundaries of the pilot study areas, and within the slope category of  $>5^\circ$  (Figures 6 and 7).

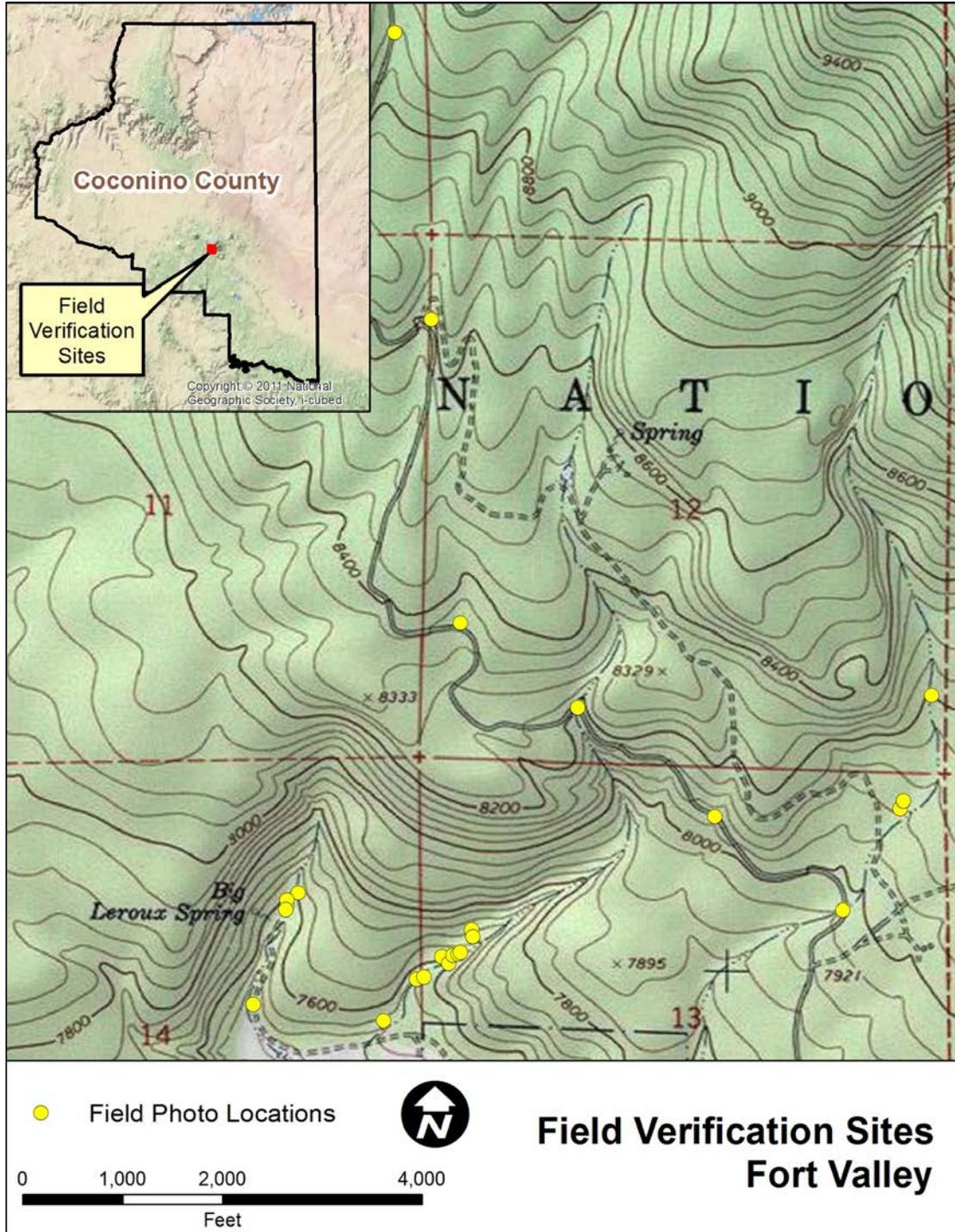


Figure 2. Field verification sites in the Fort Valley pilot study area.

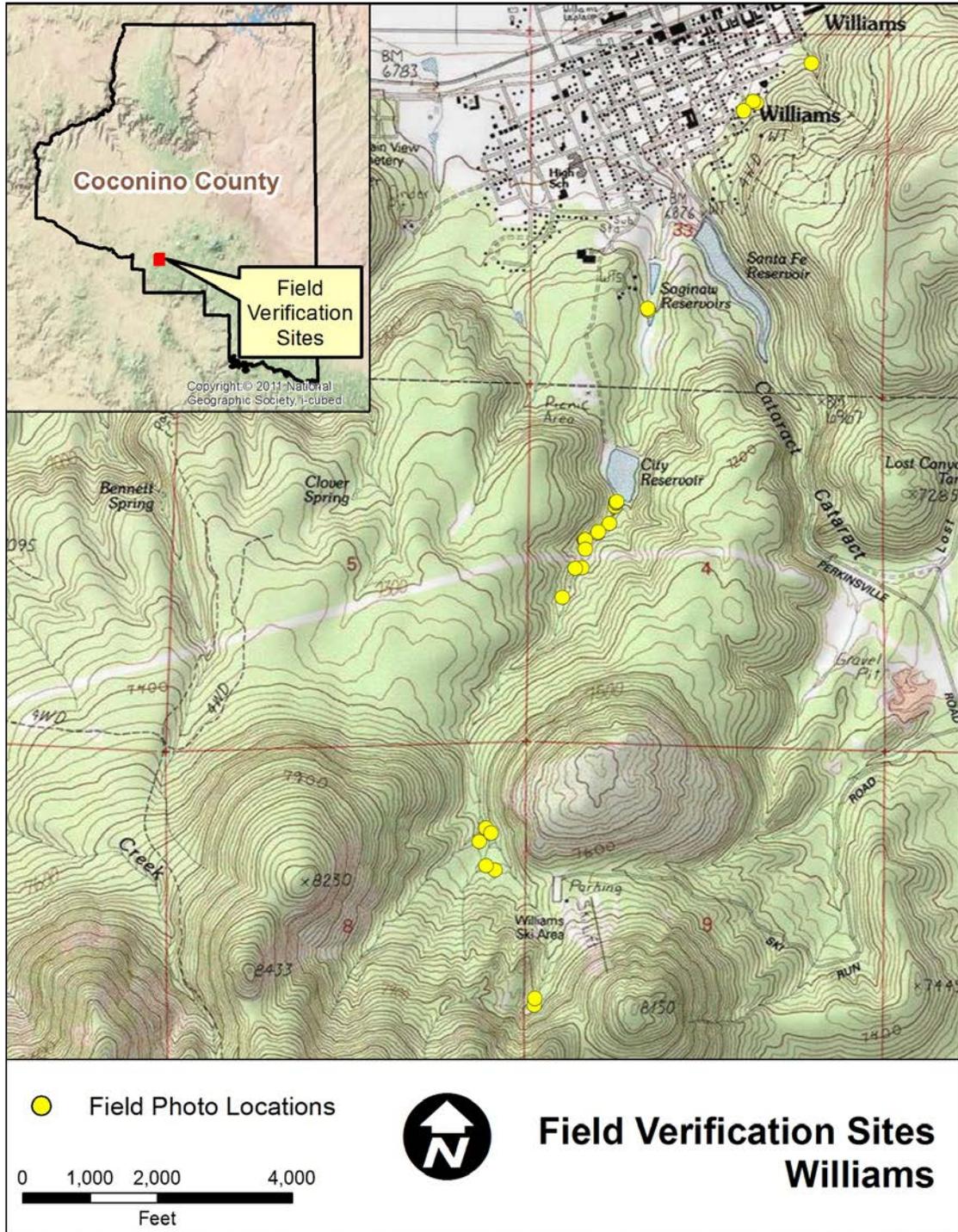


Figure 3. Field verification sites in the Williams pilot study area.

All of the likely debris-flow deposits we observed in the study drainages had surface characteristics, such as weathering rinds and lichen growths, that indicate these deposits are not historical ( $< \sim 105$  yrs) but could be geologically young, perhaps late Holocene ( $\sim < 2000-3000$  yrs).



Figure 4. Linear boulder deposits interpreted to be debris-flow levees. Panel A: Fort Valley (A. Youberg). Panel B: Bill Williams Mountain (M. Kellogg).



Figure 5. Bulbous boulder deposits interpreted to be debris-flow snouts/terminal lobes. Both photo taken in the north Fort Valley pilot area. Panel A: View looking upstream at two terminal lobe deposits (photo: A. Youberg). Panel B: Positive relief morphology with steep front typical of terminal lobes (photo: M. Kellogg).

### Comparison of Findings with Tasks 1

During Task 1 we made several assumptions regarding the possibility of post-wildfire debris-flow hazards, some of which apply to this task. First, we assumed that the pilot watershed would likely have extensive areas of moderate to high burn severity when a wildfire occurs (more on this topic in Task 5). Second, we assumed that areas with slopes  $> \sim 5^\circ$  are hazard zones that incorporate debris-flow initiation, transport and runout zones. Third, we assumed that areas with slopes  $< \sim 5^\circ$  have a low potential for debris flows but a high hazard from the direct impacts of debris flows including sediment-laden flood flows that can travel much farther down slope than debris flows typically do. And finally, we assumed that a 100-m buffer along channel of concern would adequately capture the debris-flow hazard zones. During Task 2 we used these, and other criteria as explained in the previous memorandum (Loverich and Kellogg, 2016), to select the two pilot study areas of Fort Valley and Williams.

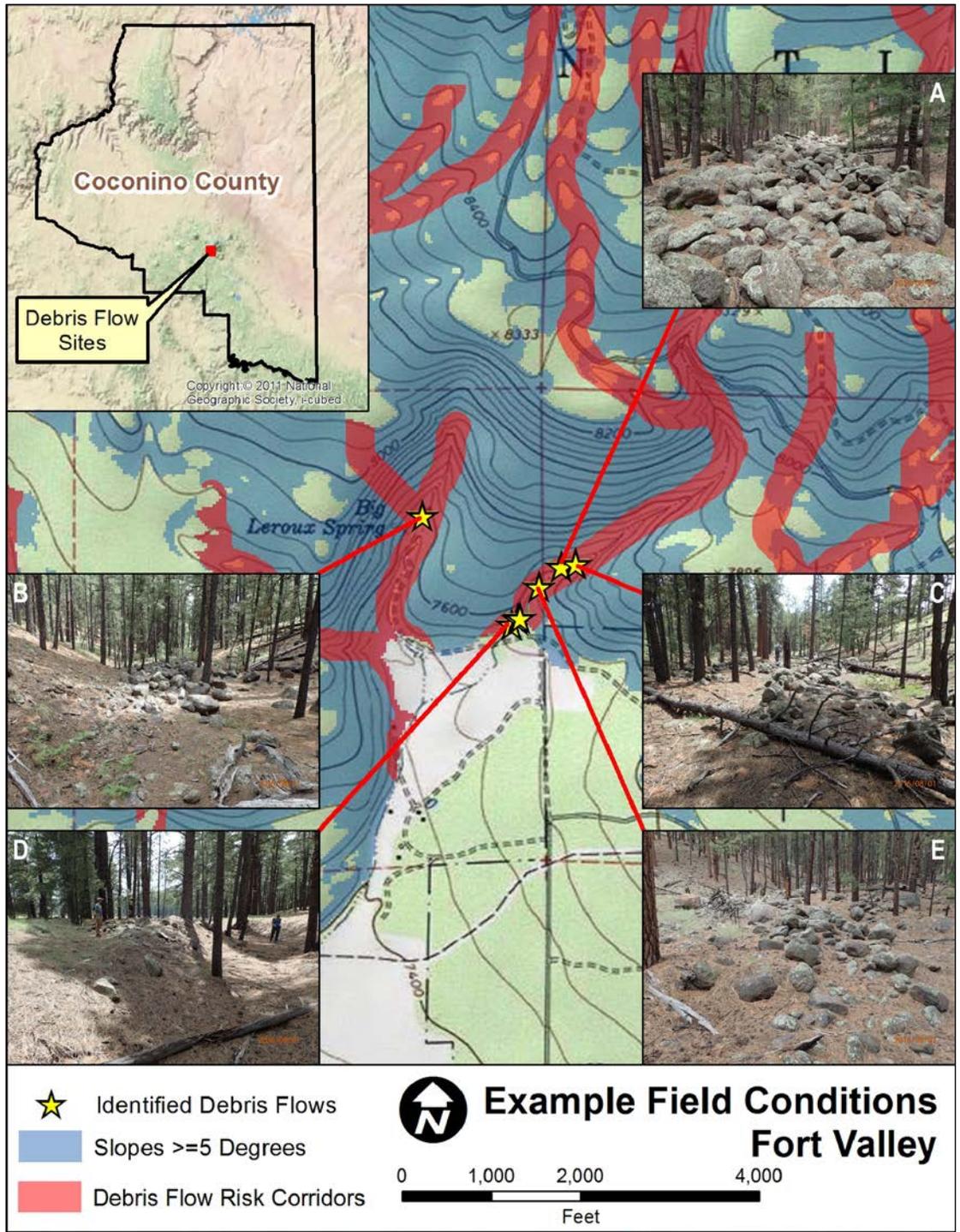


Figure 6. Debris-flow corridors with slope categories and example field sites in Fort Valley.

Observations of field conditions made during the reconnaissance investigation correspond well with assumptions made during Tasks 1 and 2. We found numerous boulder deposits within our assumed  $> 5^\circ$  slope category and within the 100-m buffer zones of most debris-flow corridors we assessed in each study area. While the deposition of many of these boulder deposits were likely related to debris flows (Figure 6, photos A and C; Figure 7, photos A, B and D), others were more ambiguous (Figure 6, photos B

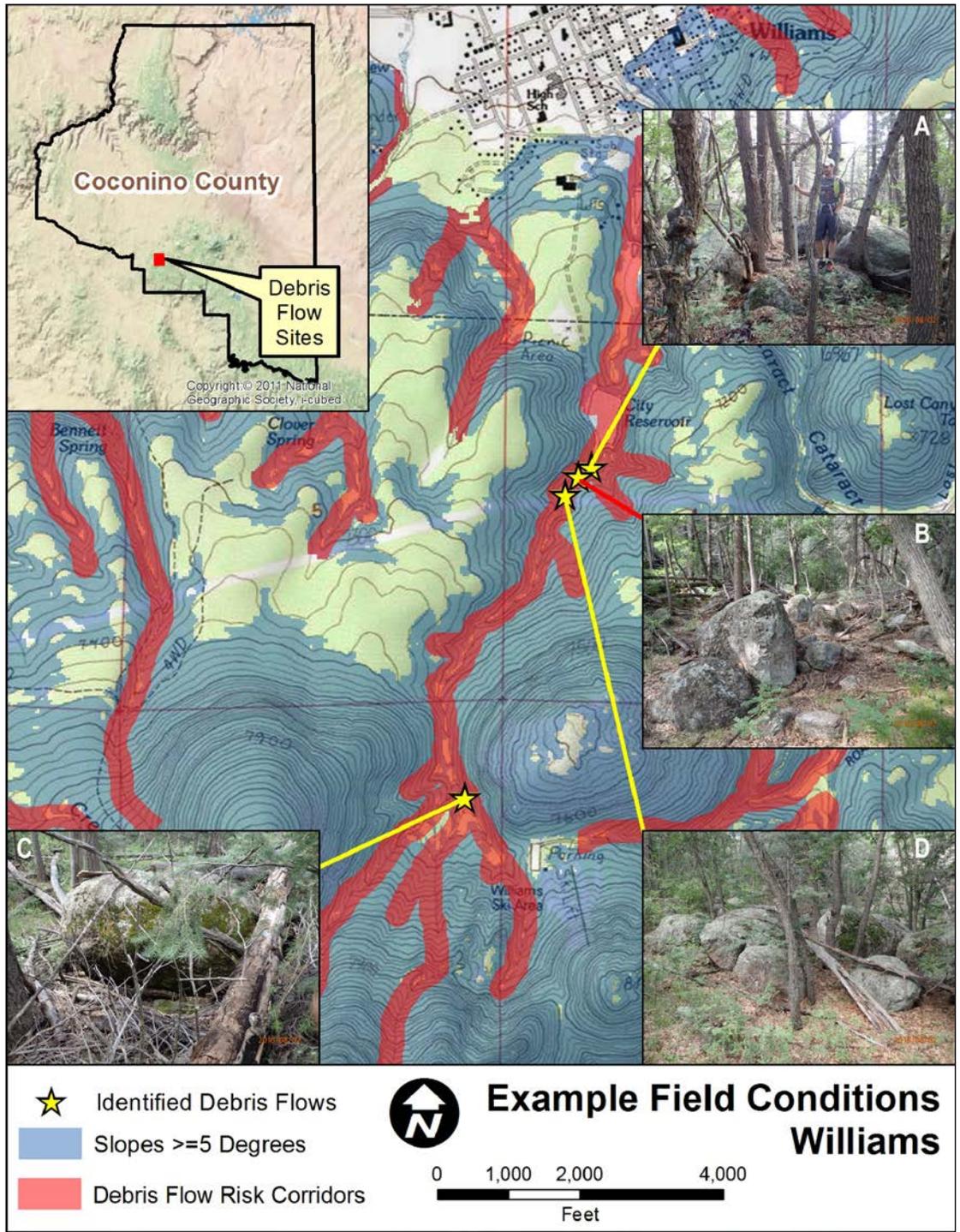


Figure 7. Debris-flow corridors with slope categories and example field sites in Williams.

and D; Figure 7, photos C), and some channel sections had no visible boulder deposits (Figure 6, photos D). Additionally, we did not observe any boulder deposits in the  $< 5^\circ$  slope category zone but observations in these areas were limited. The absence of boulder deposits does not necessarily correspond to the absence of past debris flows, as subsequent flood flows or deposition may have removed or covered previous deposits. The presence of debris-flow-like boulder deposits, however, strongly suggests that

debris flows occurred in the past and can occur in the future. And, importantly, all of the channel sections that were visited had stored sediment that are available for transported should a debris flow initiate higher in the watershed (e.g. Figure 6, photos B and D).

## **CONCLUSION**

We documented likely debris-flow deposits in both pilot study areas in most channels we assessed, and the observed deposits appear to agree well with the assumptions made in Task 1 – County Wide Assessment. These deposits are not dated but are likely geologically young. Evidence of debris flows were limited to the base of channel areas and fan apexes. Deposits far from the channels were not observed, but may be present, and additional deposits may be identified with the to-be-acquired LiDAR data. Although debris flows may not travel far beyond the fan apex, sediment-laden floods will, and these flows will be exacerbated by the occurrence of debris flows.

The next steps include assessing study channels for the likelihood of post-wildfire debris flows using the burn severity modeling results and a new USGS post-fire debris-flow equation to assess probability of debris flows. Other next steps include modeling with LAHARZ and the high resolution LiDAR data, to be acquired, to assess potential runout distances from the base of channels with a variety of likely debris-flow magnitudes

Sincerely,

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CC: Joe Loverich, PE, CFM; JE Fuller/Hydrology and Geomorphology, Inc.  
Mike Kellogg, PG, CFM, GISP; JE Fuller/Hydrology and Geomorphology, Inc.

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