Landslides are Surprisingly Large and Widespread in Arizona

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Introduction

The Arizona Geological Survey (AZGS) has been compiling a statewide landslide database for hazard mitigation planning. The AZ Statewide Landslide Inventory Database (AZSLID) contains landslide and mass movement data from published maps and reports as well as newly documented slides identified while building the database. The proximity of landslides to critical infrastructure, utilities, and populated areas is important information not easily accessible prior to creation of the database. AZSLID will be useful to state, local, county, and tribal governments for hazard mitigation and planning purposes.

Current status of AZSLID database

- Landslide features imported from >100 geologic maps and reports
- More than 6,000 landslide feature polygons in AZSLID database. Slides occur in each county throughout AZ.
- 10% of these do not appear on existing geologic maps. These new landslide features were digitized based on Google Earth and aerial photo interpretation
- Most undocumented landslides are found on Tribal Lands and account for ~48% of the total landslide feature area in AZSLID
- 1,380 landslide and debris flow observation and data points
- Landslides in AZ occur predominantly along steep and mountainous terrains, canyons, and basalt-capped mesas
- Landslide hazards documented in AZSLID will be used to update the AZ state hazard mitigation plan

InSAR landslide monitoring

Interferometric Synthetic Aperture Radar (InSAR) is a radar technique used to generate maps of surface deformation. Using a pair of InSAR frames, an interferogram can be created which shows elevation differences between the data frames. InSAR techniques are capable of measuring cm-scale levels of deformation and land subsidence.

Movement along the edge of the Echo Cliffs is captured in an InSAR interferogram spanning July 2007 to October 2009. Highway 89 is built upon a complex of landslide blocks in this area. Reactivation of a small portion of the complex resulted in extreme damage to the highway in February, 2013.

More than \$60 million in federal emergency relief funds were used to investigate the cause of failure and repair the highway.

Movement of an existing landslide feature along the northern Vermillion Cliffs is recorded by the same InSAR interferogram as the US89 slide. Here, one portion of the extensive landslide complex has reactivated. Repeat collection of InSAR data is useful for determining the amount and extent of movement over time.

Unmapped slides on AZ Reservation lands

Many landslides in NE AZ, located on Tribal Lands, do not appear on existing geologic maps

Hundreds of landslides in AZSLID are undocumented slides within the Navajo and Hopi Reservations that were characterized through Google Earth and aerial photo interpretation

Many of these landslide features rival well-known and studied landslide locales such as the Vermillion Cliffs

Impressive Toreva Block landslide complexes are present within and along the eastern flank of Black Mesa in the Navajo and Hopi American Indian Reservations in NE AZ

The geologic setting, ideal for landslide formation, is highly erodible Mancos Shale capped by erosion-resistant Mesaverde Sandstone

Balakai Mesa lies to the south of Black Mesa. The geology and setting is similar and similar-scale landslide complexes are common

Here, a more recent landslide or a reactivation of an existing slide is located adjacent to much older landslide deposits

Almost the entire perimeter of Balakai Mesa is defined by Toreva block landslide complexes

InSAR data spanning September 2009 to April 2015 captured movement in fine grained Painted Desert sediments near Hwy 87 in Navajo County, AZ. This example demonstrates the utility of InSAR for subtle ground movement detection. Nothing is evident of failure in aerial imagery yet the ground surface has subsided. Continued InSAR data collection provides quality monitoring of known landslide-prone terrains.

Aerial view of Mormon Flat Dam and AZSLID landslide polygon

Oblique aerial view of Mormon Flat Dam and adjacent landslide. Image captured via drone.

Oblique aerial view of Mormon Flat Dam and adjacent landslide. Image captured via drone.

Digital Elevation model of Mormon Flat landslide created from 97 drone-collected images compiled using Agisoft structure from motion software. Resolution is ~12 cm/pixel with ~70 points per m².

Mormon Flat Dam and drone-based landslide reconnaissance

Previously mapped landslide adjacent to Mormon Flat Dam on the Salt River, AZ

AZGS geologists revisited the slide in 2016 to characterize landslide feature in greater detail

DJI Phantom Pro III drone was used to photograph the landslide from many angles

A DEM of the landslide was created using Agisoft photogrammatic structure from motion software. Resolution was ~12 cm/pixel with ~70 points/m²

AZGS report on the landslide is pending

Important to reassess known and suspected slides near important infrastructure (highways, freeways, populated areas, flood retention structures, etc)

Brian Gootee piloting the DJI Phantom Professional III (different field area)

Recent debris flow activity near Littlefield, AZ

Dramatic debris flow initiation and associated alluvial fan flooding occurred in the Virgin Mountains near Littlefield, AZ following heavy rains in September, 2014. Debris flow initiation points, chutes, and deposits can be added to AZSLID based on interpretation of before/after aerial imagery. Additional field verification and mapping would add important detail to AZSLID. Inclusion of data such as these to the database is valuable for local communities affected by these events.

Image set A taken in May 2013 and predates debris flow event

Many debris flow chutes are already apparent in the steep terrain of the Virgin Mountains

Inclusion of this type of debris flow-prone landscape into AZSLID is important for monitoring and hazard awareness purposes

Repeat examinations for landscape changes is useful for determining local threshold rainfall values

Image set B taken in June 2015 and reflects the landscape soon after debris flows occurred

Extensive modification of the alluvial fan channel system above and near Littlefield is reflected

Differentiation of debris flow presence before and after the rainfall event is a useful addition to AZSLID

Awareness of the extent of all geologic hazards is never a bad idea