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A mitigation perspective on three GIS case studies on post-fire debris flows along the Wasatch Front, Northern Utah

Abstract

The combination of wildfire and landslide debris flow risks along the Wasatch Front in Utah are post-fire debris flows. In an effort to better understand this natural hazard and the subsequent emergency response, three post-fire debris flows case studies are analyzed in ArcGIS. The investigation will include the environmental circumstances surrounding the wildfire and debris flows, such as triggering rainfall amounts, slope of the burn scar and soil type. In addition, the emergency mitigation response will be evaluated with a brief look at human and structural vulnerabilities. The debris flows were caused from wildfires that occurred from months up to a year prior to the debris flow event, with acres burned ranging from 1,800-8,000. Triggering rainfall amounts were between 0.58 and 1.58 inches. The mean slope of the fire perimeter burn scars is 24.3°. All soils were loam-types. The areas were all known to have landslides hazards and mitigation efforts were treated as such. Once the wildfires took place, each area was closely monitored for potential debris flows and some underwent mitigation techniques, but damage and evacuations still occurred when intense thunderstorms hit. There were no fatalities or injuries, but there was mild to moderate property and home damage.

Introduction

The Wasatch Front urban area in Northern Utah is nestled against the abruptly rising Wasatch Mountains to the east. This geography has created a landscape that is highly prone to debris flow hazards. Utah is also a very arid which creates a high susceptibility to wildfires. The combination of these risks are post-fire debris flows. In recent history, Utah landslides have caused more than $261 million in damage (Eldridge et al. 2008). Debris flows are a type of landslide that contain larger debris, such as tree trunks or boulders, and can travel long distances quickly (USGS, Figure 1).

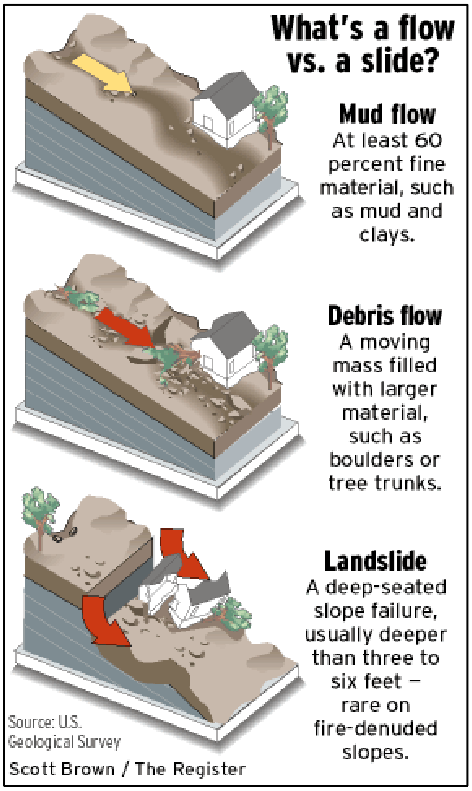

Figure 1. Description of landslide types (USGS).

The Wasatch Mountains are an uplifted mountain range that contributes the necessary steep slopes and rainfall that trigger landslide events. Wildfires create vulnerably of debris flows by removing the vegetation-glue that holds debris together and lowering the thresholds of a triggering event. Utah is plagued with landslides and has a long history of destructive landslides. Figure 2 shows past debris flows and the susceptibility along the Wasatch Front (Utah Geological Survey). Because landslides are so prominent in Utah an extensive emergency response system is in place.

Utah fire management depends on where the fire occurs, either the United State Forest Service (for federal lands), Division of Forestry, Fire & State Lands via County Fire Wardens (for state lands) or local fire departments (for city land). Once the fires are put out, Burned Area Emergency Response teams assess subsequent threats and implement burn scar treatments (Napper, 2006). These teams warn of potential vulnerable areas at risk for post-fire debris flows and suggest mitigation measures (McInerney, 2009). State department specialists, such as geologists at the The Utah Geological Survey and soil scientists at the local Forest Service also play a coordinated role in evaluating landslide potential. Once a debris flow event has occurred it is managed, in part, with the Utah Division of Emergency Management.

The purpose of this paper is to use ArcGIS to examine three recent post-fire debris flow case studies as an exercise in post-fire debris flow mitigation. Three wildfires and subsequent debris flows were chosen at random where enough GIS and census data was available. These three northern Utah, Wasatch Front events are the following:

1. Santaquin “Mollie” fire in August 2001 and following debris flow in September 2002
2. Farmington fire in August 2003 and following debris flow in April 2004.
3. Saratoga Springs “Dump” fire in June 2012 and following debris flow in September 2012.

The locations of the wildfires and subsequent debris flows are in Figure 2.

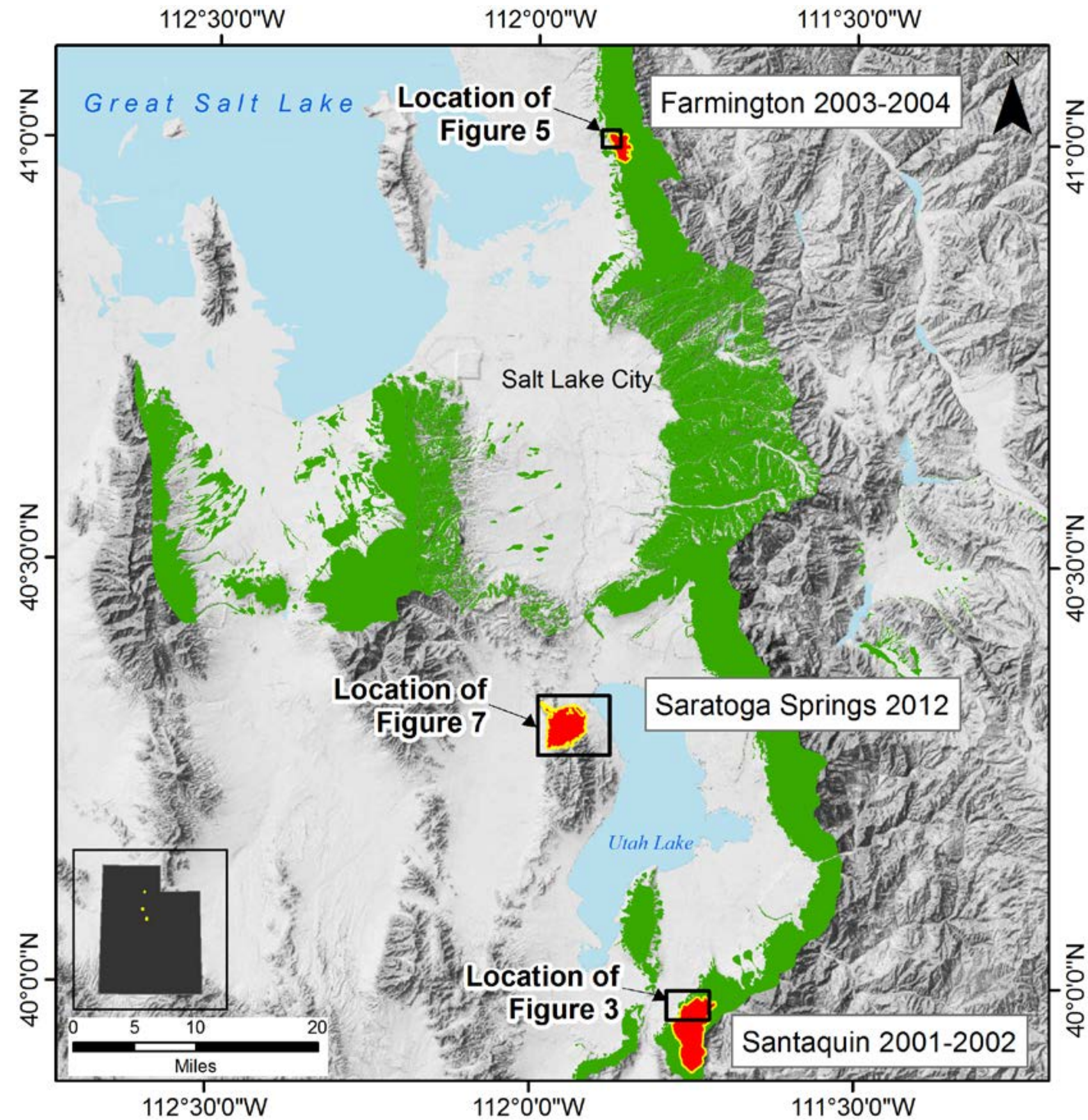

Figure 2. Base map showing debris flow hazard areas (green) and fire perimeters (red) for the three case studies along the Wasatch Front, northern Utah. Boxes indicate locations of Figures 3, 5 and 7. Hillshade data from the Utah AGRC.

Data and Methodology

GIS data were available from multiple sources. The following are the sources for the wildfire perimeter GIS data:

1. August 2001, Mollie Fire: The Geospatial Multi-Agency Coordination Group (GeoMAC)
2. July 2003, Farmington Fire: digitized from USGS map (Giraud and McDonald, 2004)
3. June 2012, Dump Fire: The Geospatial Multi-Agency Coordination Group (GeoMAC)

The following are the sources for the post-fire debris flow perimeter GIS data:

1. September 2002, Santaquin Debris Flow: Utah Geological Survey (UGS)
2. April 2004, Farmington Debris Flow: Utah Geological Survey (UGS)
3. September 2012, Saratoga Springs Debris Flow: Utah Division of Emergency Management ,digitized evacuation zone and flow path from(debris perimeter not available)

Parcel data, digital elevation model's (DEM), weather station locations and soil data are from the State of Utah. Historical daily precipitation data are from National Oceanic and Atmospheric Administration (NOAA). The average slope was calculated in ArcGIS using the Spatial Analyst tool and the DEM that was clipped on the fire perimeter feature. Because of their clay content, loam soil types (equal parts of clay, sand and silt) are less permeable and have a higher water capacity than just gravel or sandy soils, (FAO and UNL) making them easier to become saturated with water and contributing to triggering a debris flow. Housing occupancy and home value data were taken from both the 2000 and 2010 US Census. In addition, specific details related to each case study were acquired through various internet news reports, community newsletters, and professional hazard analysis articles.

While many factors contribute to debris flows, including burn conditions, rainfall intensity, basin and channel characteristics, and this paper will only focus on rainfall, slope steepness and debris type.

Results

2001-2002 Santaquin Wildfire and Debris Flows

The “Mollie” wildfire occurred in Utah County near the city of Provo (Figure 3) in August 2001 and burned approximately 8,000 acres. The burn scar was seeded and mulched by the U.S. Forest Service but it didn’t take root quickly enough. A post-fire mitigation plan to build diversion channels to offset landslide hazards was planned but wasn’t completed due to time and financial restraints (Giraud and McDonald, 2002).

On September 12, 2002 the post-fire debris flow occurred releasing more than 20,000 cubic yards of sediment on the residents below that lived in the path of drainage channels (Giraud and McDonald, 2002). Rainfall from the previous day of 0.58 inches triggered the event. The soil type was loam. The landslide took place on the west side of Dry Mountain, at the foothills of the Wasatch Front, with an average slope of 26.8° (Figure 3). As is normal with quick traveling debris-flows, there was little warning and structure damage occurred.

No injuries or deaths were reported but the debris flow caused damage to 20 houses, taking 3 off their foundations (McInerney, 2009) and caused approximately $500,000 in damage (Giraud and McDonald, 2002). ArcGIS analysis determined that 89 parcels (from 2000 census) intersect the debris flows. Figure 4 shows examples of damage from the debris flows. Census data from 2000 reveals that an average of 4 people live per house and home values average approximately

$150,000. After the debris flows, mitigation precautions were taken more seriously including digging diversion channels (Smithsonian Institute).

A worst case scenario vulnerable risk assessment can be roughly estimated. Based on geographic analysis only, damage could have been up to $13,261,000 if there was a total loss to housing (89 parcels multiplied by $149,000) and fatalities as high as 356 people (4 people in 89 parcels). Given that the census data was taken from 2000, these values would most likely be higher today.

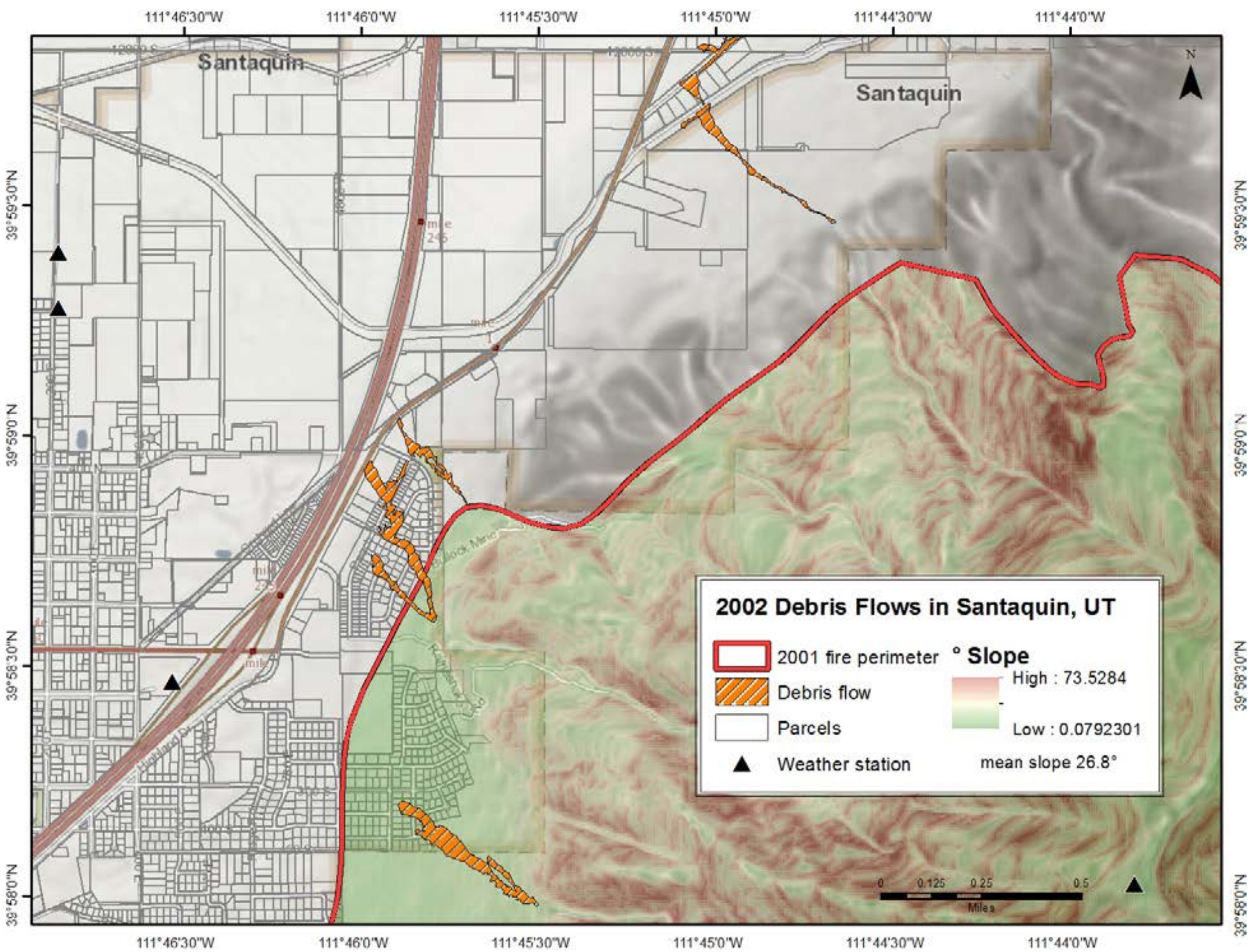

Figure 3. Index map of the debris-flows from 2002 for Santaquin, Utah. See Figure 2 for location.

Figure 4. Photos of damage from the Santaquin 2002 debris flows (Utah Valley University).

2003-2004 Farmington Wildfires and Debris Flows

The Farmington wildfires occurred in Farmington of Davis County (Figure 5) in late August 2003 and burned approximately 1,800 acres. Landslide mitigation measure were recommended including planting vegetation and some diversion structures were already in place as previous precautions.

The debris flow in Farmington occurred a year later on April 6, 2004. Approximately 4,000 cubic feet of sediment flowed down to the residents (Giraud and McDonald, 2002). The triggering rainfall the day before was 1.58 inches and the average slope steepness was 26.1° for the burned area. The soil type was gravelly loam.

No was one injured but the flow damaged multiple homes, property and infrastructure (Giraud and McDonald, 2002 and McInerney, 2009). ArcGIS analysis indicates 4 parcels (from 2000 census) intersect the debris flows. Figure 6 shows debris flow damage photos. Davis County has the highest incident rate of debris flows than any other along the Wasatch Front (Giraud). This long-standing history of landslide hazards provokes a quick response time from multiple agencies including the Utah Geological Survey, the U.S. Forest Service and the U.S. Natural Resources Conservation Service and most of the larger drainage basins have protective measures. Smaller ones, such as the Farmington in 2004 debris flow did not. Census data from 2000 state that there are about 4 people living per household and with an average home value of $255,000.

A worst case scenario vulnerable risk assessment can be roughly estimated. Based on geographic analysis only, damage could have been up to $1,020,000 if there was a total loss to housing (4 parcels multiplied by $255,000) and fatalities as high as 16 people (4 people in 4 parcels). Given that the census data was taken from 2000, these values would most likely be higher today.

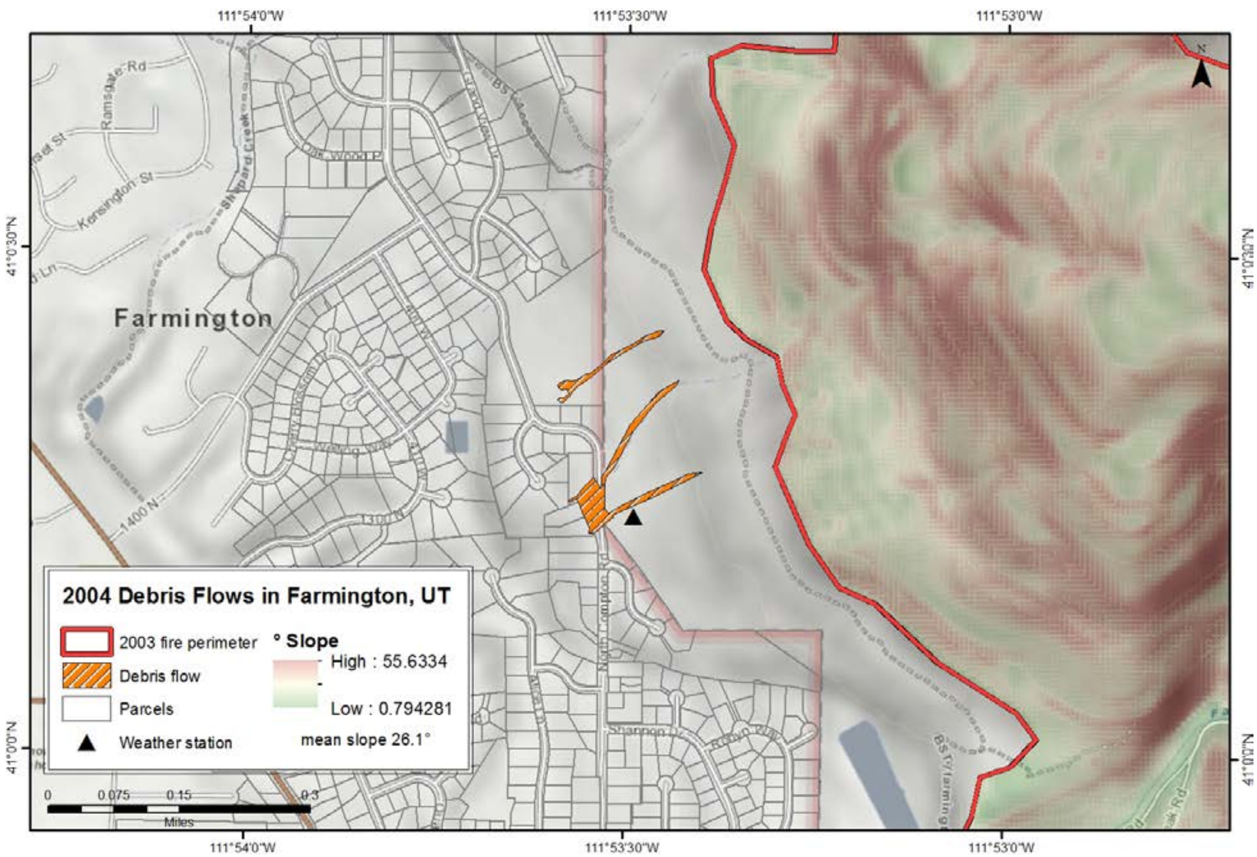

Figure 5. Index map of the debris-flows from 2004 for Farmington, Utah. See Figure 2 for location.

Figure 6. Photos of damage from the Farmington 2004 debris flows (KSL and UEN).

2012 Saratoga Springs Wildfire and Debris Flows

The "Dump" Fire or Saratoga Springs Fire burned 6,000 acres in June 2012 near the community of Saratoga Springs and Eagle Mountain, in Utah Country (Figure 7). After the fire, emergency assistance was requested to install mitigation measures, but the debris-flow occurred just a few months after the fire, before anything could be installed.

The debris-flow occurred on September 1, 2012 in Israel Canyon above the Saratoga Springs community. It unleashed approximately 11,000 tons onto the residential area (out of the 70,000 tons released) and prompted the evacuation of 9,000 people. Rainfall of 1.25 inches during twenty-five minutes, triggered the event. The average slope of the burn scar was just 20.0° (Todea, 2015). The soil type was stony loam. ArcGIS analysis indicate 2889 parcels intersect the approximated evacuation zone.

The debris-flow flooded basements with mud and damaged houses but there were no injuries. Figure 7 shows examples of damage from the debris flow. After the debris flow there have been numerous mitigation projects including improving existing drainage channels, clearing out the overfilled detention basin, creating spillways etc. According to the 2010 census data, an average of 4 people live in a residence with average homes values at $268,000.

A worst case scenario vulnerable risk assessment could be roughly estimated. Although evacuations zones are larger than effected areas, even if 1% of these parcels were hit by the debris flows, based on geographic analysis only, damage could have been up to $7,500,000 if there was a total loss to housing (28 parcels multiplied by $268,000) and fatalities as high as 112 people (4 people in 28 parcels).

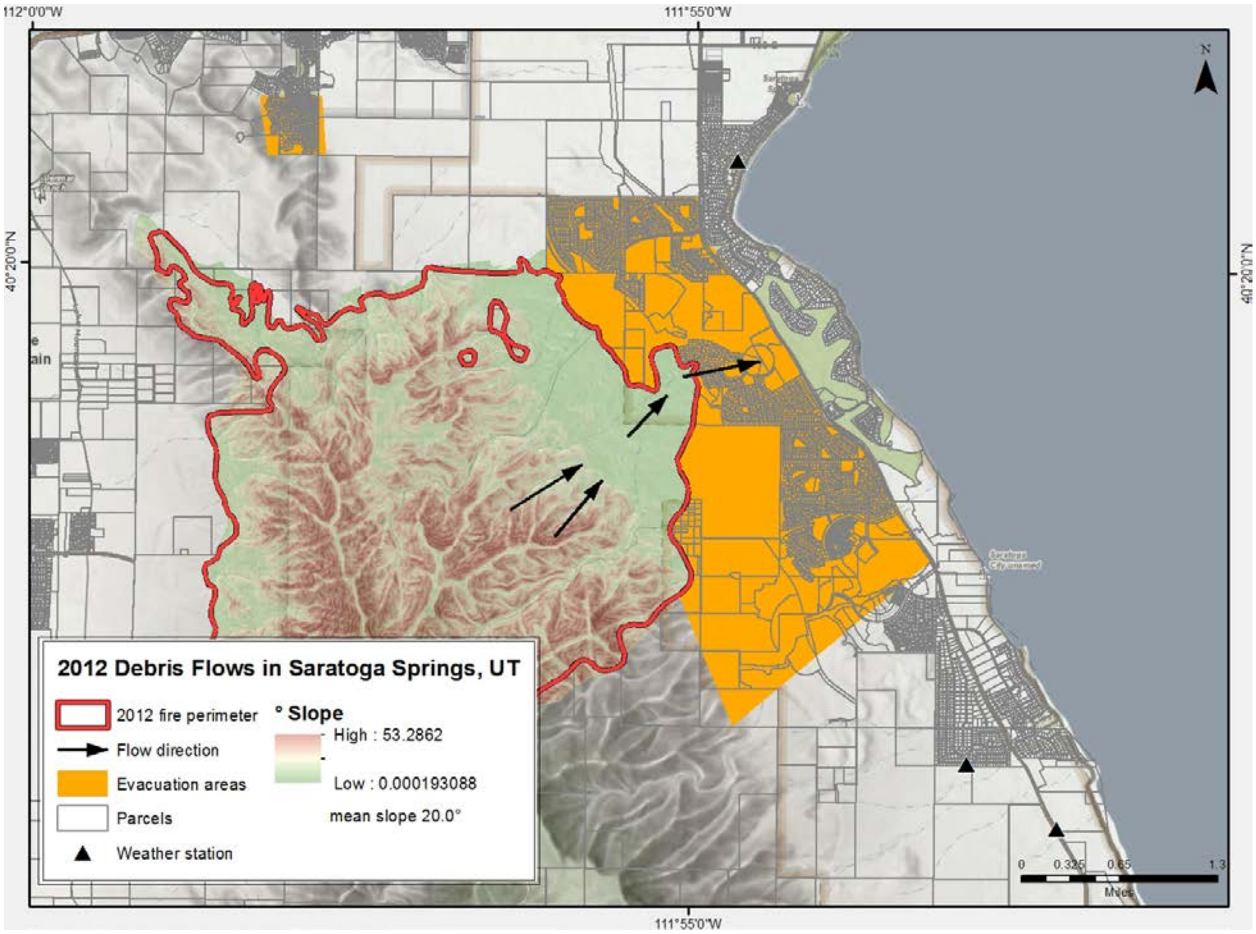

Figure 7. Map of the debris-flows from 2012 for Saratoga Springs, Utah. See Figure 2 for location.


Figure 8. Photos of debris flow damage from Saratoga Springs, 2012 (DEM)

Conclusion

Due to its geology, landslides are one of the most common hazards in northern Utah. When wildfires strip the vegetation, the remaining burn scar is very susceptible to slope failure and increases the landslide risk even more. Debris flows are so dangerous because they are fast and carry such heavy debris. Studying three recent post-fire debris flows has revealed how important effective emergency mitigation is. The three post-fire debris flows are shown in Figure 2 and Table 1 lists the details of each. The mean slope of the areas burned are all less than the 30° and the triggering rainfall amount before the debris flows is less than 1.58 inches. So even a shallow slope increases the debris flow potential of a burn scar significantly and especially when it becomes saturated with a moderate amount of water. All soils were loam types. Fortunately, no one was seriously injured or killed in these case studies and limited moderate structural damage occurred. Mitigation vulnerability is difficult to ascertain, but before these events happened, just by overlying the drainage basins of fire perimeters with parcel data, and then debris flow areas with parcels, a worst case scenario could be conducted (Table 2).

By comparing damages from Table 1 and Table 2, current mitigation and emergency response measures are clearly working. With landslide risk along The Wasatch Front being so high, the persistence of emergency response agencies, teams and individuals has hindered the potential fatal outcome of post-fire debris flows.

City, year	Acres Burned	Mean Slope of Fire Perimeter	Soil Type	Triggering Rainfall Amount	Housing Value	# House Occ.	Damage Reports
Santaquin 2001 - 2002	~8,000	26.8°	Silt, sand and clay (loam)	0.58 inches	$149,200	~ 4	Damaged 20 homes with 3 knocked off foundations ~$500,00 damage
Farmington 2003 - 2004	~1,800	26.1°	gravelly sandy loam	1.58 inches	$255,800	~ 4	No injuries, multiple homes damaged infrastructure, property, and houses
Saratoga Springs 2012	~6,000	20.0°	Stony loam	1.25 inches	$268,350	~ 4	Minor damage to homes, moderate damage to infrastructure

Table 1. Wildfire and debris flow characteristics, housing census data and debris flow damage reports.

City, year	Housing Value	# House Occ.	# Intersecting Parcels	Possible Fatalities	Possible Damage
Santaquin 2001 - 2002	$149,200	~ 4	89	356	$13,261,000
Farmington 2003 - 2004	$255,800	~ 4	4	16	$1,020,000
Saratoga Springs 2012	$268,350	~ 4	28 (1% of 2889)	112	$7,500,000

Table 2. Worst case scenario vulnerability risk assessment. Possible fictional mitigation estimates if calculated at time of debris flow event and based on geography alone.

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