TECHNICAL MEMORANDUM

Alluvial Fan Evaluation:
Fans 44, 45, 78, 79, 81, 82, 115 and 116
Carson City and Douglas Counties, Nevada

To: Carson City Subconservancy District (CWSD)

From: Lewis E. Hunter, Ph.D., PG, Senior Geologist
& Geology Regional Technical Expert
Geology Section, Sacramento District

Bridget Floyd, P.G., Geologist
Environmental Design Section
Sacramento District

Date: 27 March 2020

Scope:

Floyd et al. (2017) conducted a reconnaissance level evaluation of alluvial fans along range fronts in Lyon, Douglas, Storey, Alpine and Carson City counties, Nevada. Their evaluation focused on developing an inventory of fans and evaluating their risks related to channel avulsion, debris flows, and consequences to infrastructure. Lists and maps of these fans were provided to partnering agencies in the Carson Water Subconservancy District (CWSD) providing an inventory of fans and qualitative risk. Phase II of the study aims to provide a more detailed evaluation of select fans identified by the partnering agencies. This analysis is intended to provide the basic information to satisfy Stages 1 and 2 of *Appendix G: Guidance for Alluvial Fan Flooding Analysis and Mapping* (FEMA 2003). The primary step missing in this report from the FEMA guidance is mapping the 100-yr flood limits for Stage 3. This evaluation is provided in a report by the Walla Walla District, U.S. Army Corps of Engineers (USACE 2020).

An initial six fans were identified by the CWSD includi ng two fans in Carson City County located on the east side of Prison Hill and four fans in Douglas County located on the east side of Indian Hills (***Figure 1***). At the completion of the study, funding was available to add additional fans to the investigation. In October 2019, two fans near Genoa, NV were added. All of the fans emanate from narrow valleys entrenched into fault controlled range fronts that discharge water and sediment into the Carson River Valley.

One of the prerequisites for the study was that Light Detection and Ranging (LiDAR) data needed to be available for each fan. LiDAR provides high-resolution topographic data from which the morphology of the fans could be evaluated. LiDAR data were acquired as the initial step of the study and form the baseline from which fan boundaries and surface characteristics could be analyzed. Digital elevation models (DEM) were made for each fan, as were contours to aid in surface evaluation and feature delineation.

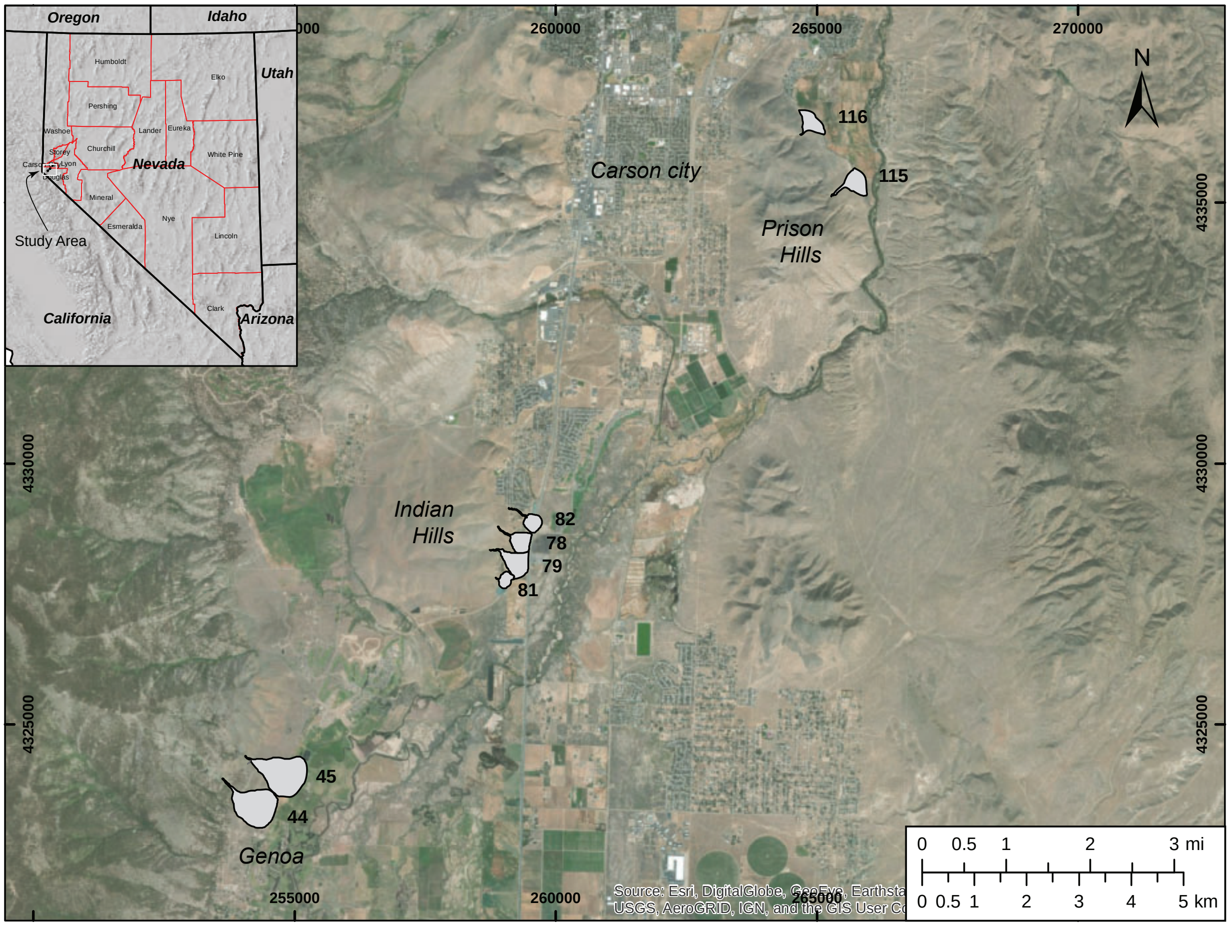


Figure 1. *Carson City and Douglas Counties, Nevada alluvial fans evaluated during Phase II investigations. Fan numbering follows that of Floyd et al. (2017).*

Following the initial desktop evaluation of the six fans near Indian Hills and Prison Hill, a site visit was preformed to get a reconnaissance level view of the fans. This site visit was conducted on 29 – 30 August 2019 to validate and augment the finding from the desktop evaluation. The two additional fans near Genoa, NV were visited between 11 – 12 December 2019. Courtney Walker from Douglas County accompanied the site visit, which focused on the Genoa fans on December 11 and then shifted to the four fans near Indian Hills (Douglas County) on December 12. As the project was winding down at that time, no site report was generated on the second site visit and the observations are incorporated into this report.

Background:

The Carson River flows east from the Sierra Nevada Mountains into the Carson Sink. The Carson River watershed includes portions of Douglas, Carson City, Washoe, Lyon, Storey, and Churchill counties, as well as a small portion in Alpine County, California.

The region is arid and mountainous, located near the western boundary of the Basin and Range Physiographic Province. Fault controlled mountain range fronts and deep alluvial basins are characteristic of this setting where alluvial fans are ubiquitous, forming where mountain valleys terminate along steep, fault controlled mountain fronts. Alluvial fans typically develop through a balance of sediment-rich (hyperconcentrated) flows and high-density sediment gravity flows (debris flows and/or mud flows). Hyperconcentrated flows (e.g., sediment laden stream flow) transport water and sediment through mountain valleys but once the valley confines are lost these flows can diverge and rapidly lose competence (a measure of the maximum sized particle/clast that can be transported) and capacity (e.g., net volume of sediment in transport) resulting in rapid deposition. Flows may remain channelized and/or spread out across the fan surface as sheetflow; both migrating across the fan over time causing fan aggradation. High-density sediment gravity flows also originate along the steep mountain slopes, or in over steepened reaches where loose granular material can fail when saturated during intense rainfall and/or snow melt events. Arid slopes are ideal for such events where surface soils are loose, soil development is poor, vegetation sparse, and rates are infiltration high. When these saturated sediments fail they flow down gradient en mass as high-density sediment gravity flows, which can transport material down gradient in natural levee bound channels or isolated flows that spread across the fan slope, and generally terminating in a lobate deposit. Debris flows undergo little mixing during transport and are composed of whatever material is available at the source (clay to boulders). Mudflows being less viscous have a finer particle-size distribution. Over time these flows distribute sediment radially from the source valley and build fan-shaped landforms. The ultimate shape of a fan is controlled by the space available for deposition (accommodation space) and inflow from other valleys. Fans are composed of coarse-sized particles at the source and fine distally to sand and silt. Controlling factors in fan formation include the geology, slope, soil properties, rainfall duration and intensity deposition, and fault activity.

Localized deposition and/or erosion can lead to rapid channel migration or avulsion. The balance of their respective processes dictate whether a fan is dominated by alluvial sedimentation or debris flow/mudflow deposition; however, most result from a combination of both. Furthermore, it is not uncommon that modern alluvial fans aggraded under different climatic conditions than exist today, such that portions may be relict, and relatively inactive in today’s climate. Tectonic uplift and changes in stream discharge (both in terms of water and sediment load) further complicate the depositional history by driving phases of deposition and erosion/incision.

The dynamic nature of alluvial fans poses a high risk to developed areas located on and around the alluvial fans. In arid regions, alluvial fans have been experiencing rapid urban development, increasing risk of flood and/or debris flow damage in the watershed. This study is intended to help identify the high-risk areas of select fans. Floyd et al. (2017) identified 297 fans, or fan lobes, ranging in size from 2 acres to nearly 5000 acres; of these 64 were located in the Carson Valley-Carson River hydrologic unit. Most of the fans evaluated (67%) were listed as having a moderate risk, while 26% have a high risk. The eight fans (44, 45, 78, 79, 81, 82, 115 and 116) selected by the CWSD for analysis were all previously assigned a moderate risk classification.

Methodology:

The initial phase of the project was to acquire the GIS database used by Floyd et al. (2017) and import it into ArcGIS. The ArcGIS project serves as the base platform for mapping and data archive. The next step was to locate and download LiDAR data covering the selected fans.

LiDAR

LiDAR is a technology that uses light pulses to measure distance. When mounted on an airborne platform with high-resolution positioning equipment (e.g., GPS) and instrumentation to measure the platforms attitude (e.g., an IMU that measures pitch, roll and yaw), a LiDAR system can collects measurements that can be converted to elevation data. During the processing steps, these data are classified to separate returns off of trees, buildings, water, ground and other classes. It is the ground returns that are used to make bare-earth models that represent the ground surface with other returns being removed. Only bare-earth data was used in this study.

LiDAR data used in the study were downloaded from the U.S. Geological Survey's National Map Data Download site located at https://viewer.nationalmap.gov/basic/. These data were archived under the 3DEP program [*Elevation Source Data (3DEP – LiDAR)*]. Using the interactive map 12 tiles of LiDAR point cloud data (LAS format) were identified that cover the Prison Hill and Indian Hills areas. Subsequently, an additional 22 tiles of data were downloaded for the analysis of Fans 44 and 45 near Genoa, NV:

Indian Hills Area (Fans 78, 79, 81 & 82)
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5827_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5828_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5829_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5830_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5927_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5928_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5929_LAS_2018
USGS_LPC_NV_Reno_Carson_QL2_2017_11SKD5929_LAS_2018

Prison Hill Area (Fans 115 & 116)
USGS_LPC_NV_Reno_Carson_QL2_2017_11SKD6435_LAS_2018
USGS_LPC_NV_Reno_Carson_QL2_2017_11SKD6436_LAS_2018
USGS_LPC_NV_Reno_Carson_QL2_2017_11SKD6535_LAS_2018
USGS_LPC_NV_Reno_Carson_QL2_2017_11SKD6536_LAS_2018

Genoa Area (Fans 44 & 45)
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5122_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5123_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5124_LAS_2018

USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5125_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5222_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5223_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5224_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5225_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5322_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5323_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5324_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5325_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5422_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5423_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5424_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5425_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5522_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5523_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5524_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5525_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5624_LAS_2018
USGS_LPC_NV_Reno_Carson_QL1_2017_11SKD5625_LAS_2018

Once the LiDAR data were downloaded they were imported into the software package Quick Terrain Modeler (QT Modeler) by Applied Imagery at Johns Hopkins University. The tiles were initially viewed as point files to evaluate coverage and to determine which tiles coincided with each particular area. After evaluating coverage, the data were grouped by area and re-imported to generate separate gridded surfaces, or digital elevation models (DEMs; also referred to as digital terrain models). The software allows the user to select a sampling density to control resolution; however, it also computes a default density based on the data set provided. In each case, the default resolution was used during import to maintain the native resolution of the data: 0.29 m (0.95 ft) for Genoa, 0.3 m (0.98 ft) for Prison Hill and 0.56 m (1.7 ft) for Indian Hills.

Various products were generated once the surface models were completed. The initial product was a geotif DEM for 3-D visualization. The next products were geotif images of the shaded relief map (hillshade maps) and a color graduated elevation model. Then 1 m (3.3 ft) and 2 m (6.6 ft) contours were generated and exported as shapefiles for import into ArcGIS and LeapFrog Works. These contours were generated to provide basic reference for defining surface morphology and serve only as a visual aid during fan evaluation. Finally, a series of slope analyses were performed to see what combination of slopes best highlighted surface features. During the evaluation of the Indian Hills and Prison Hill areas four different slope models were evaluated (***Table 1***). An addition 2 slope models were evaluated for the Genoa tiles.

The bins for slope models 2 and 4 were generated to search for combinations that would enhance surface features on low angle slopes while model 3 used a slight modification to the “Mobility” slope model that is pre-programmed into the software: the modification being an additional divide at 1°. Slope 1 was used to evaluate depositional processes where

Table 1. *Breakpoints used in slope models*

	*Model**					
	Slope 1 (°)	*Slope 2 (°)*	*Slope 3 (°)*	*Slope 4 (°)*	*Slope 5 (°)*	*Slope 6 (°)*
Bin boundaries for slope models	0	0.5	1	2	2	1
	1	1	2	4	4	4
	4	2	4	6	8	6
	6	3	5.4	8	15	8
	9	4	11.3	10	20	12
	15	5	16.7	12	25	20
	90	6	24.2	15	30	30
		8	90	20	45	45
		10		30		
		15		45		
		20		90		
		30				
		45				
		90				

** Model range 0 - 90° for Indian Hills/Prisoner Hill; 0-45° for Genoa, NV fans.*

fluvially dominated fans typically exhibit slopes below 3 – 4° while debris flow dominated fans can have slopes in excess of 6 – 8° (Jackson et al. 1987). ***Figure 2*** provides a generic example of a slope maps for Prison Hill and Indian Hills areas while ***Appendix A*** is an example showing all 6 slope models[1] in the Genoa, NV area. In the analysis of Fans 44 and 45 near Genoa, NV an upper limit at 45° was used to provide additional resolution in the lower angle slope ranges. One of the reasons for developing multiple slope maps was to be able to toggle back and forth in ArcGIS to see which combination highlights certain features (e.g., fan toe, mid-fan slope, channels, and fan boundaries).

Mapping

Mapping was performed in the ESRI ArcGIS environment. Since the LiDAR data were projected in UTM Zone 11N, meters, this projection was used throughout the study. All of the georeferenced imagery (e.g., geotifs) and shapefiles generated in QT Modeler were imported into LeapFrog Works and ArcGIS, and grouped by area, and then subdivided by fan. The contours and an aerial photograph were superimposed on top of the shaded relief

1 Note that Table 1 indicates that for slope models 1 – 4 the range was from 0 – 90°; however, the slopes run for Genoa were all for the range of 0-45°.

map and used initially to refine the fan boundary. The contours provided the primary control for defining the boundaries. At the toe of the fan, the slope maps, in conjunction with the colorized hillshade map and contours were used for delineation. It should be noted that the toes as defined occurs at around 1° in slope and is more of a general boundary zone as it is difficult to definitively define a discrete boundary on such a gentle slope. The contour maps were also used to map channel boundaries and determine if there were sub-lobes on the fan and to delineate where possible. All of the fans have undergone cultural modification that locally results in slope disturbance. Cultural features causing significant deviation in contours lines were mapped. Such features consisted of building platforms, excavations/gravel pits and road cuts. A combination of the aerial photographs, shaded relief maps and contours were used to map apparent active portions of the fan.

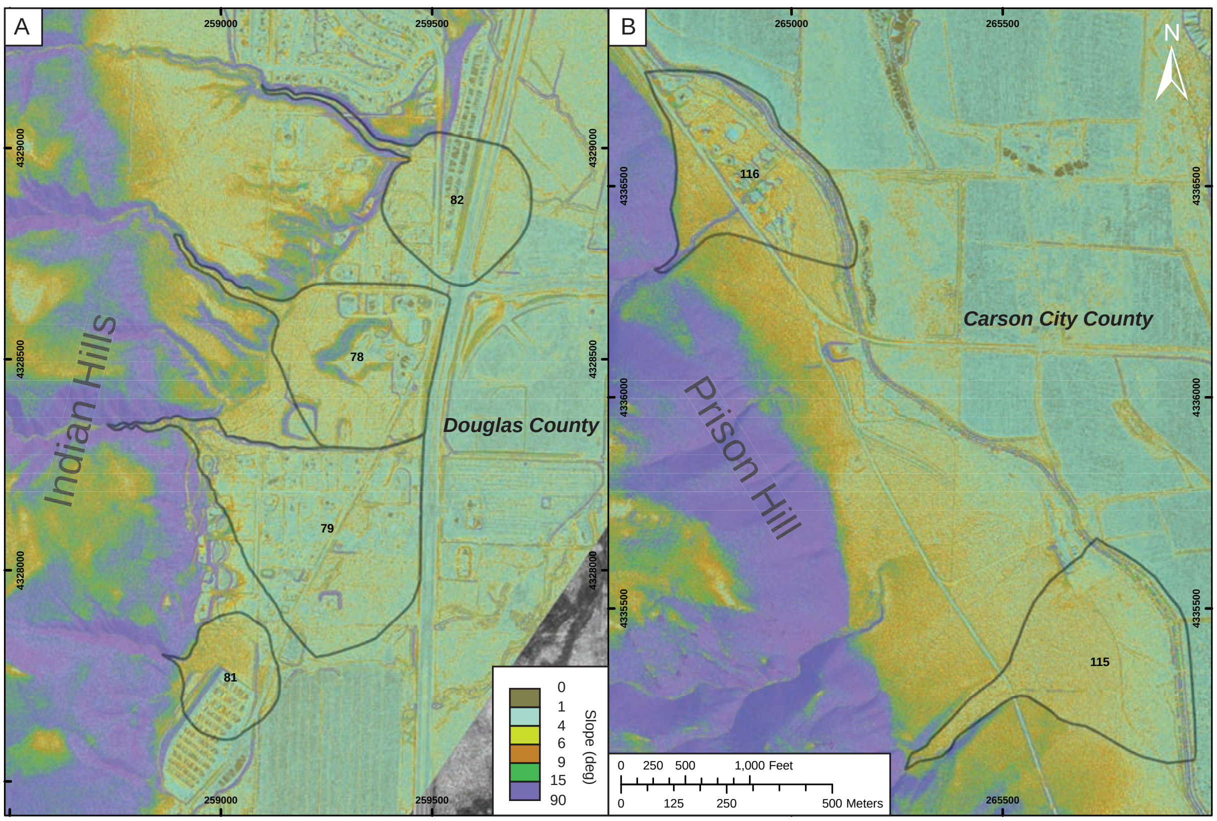


Figure 2. *Slope map of selected fans: A) Douglas County and B) Carson City County*

When the mapping was completed in ArcGIS, various layer combinations were selected and exported as georeferenced PNG files. These files were generated so they could be imported into LeapFrog Works for 3-dimentional (3-D) visualization and graphics generation.

3-Dimentional (3-D) Visualization

As with ArcGIS, all of the georeferenced maps and shapefiles were imported into the software LeapFrog Works by Seequent, LTD. The geotif DEM generated in QT Modeler was used to generate a surface model that represents the ground topography. The geotif DEM files were imported as elevation grids and select raster images were draped on each (e.g., color topography, slope maps, aerial photography, and exports from ArcGIS showing the mapping with and without contours). To enhance features, a vertical exaggeration of 2 was used for visualization.

Site Visits

An initial site visit consisting of reconnaissance level observations was performed on 29 – 30 August, 2019. The visit started in the Indian Hills area and progressed from north to south (in the sequence of 82, 78, 79, & 81). The site visit then went to Prison Hills to look at Fans 115 and 116. The extent of each visit depended on questions to resolve bases on the mapping effort and property access. Where easily accessible, the mid fan and upper fan reaches were walked following existing trails and stream pathways, with primary focus being to look at the feeder channels and areas downstream of the fan apex to see if there is evidence of active deposition and/or erosion.

A second site visit was conducted on 11 – 12 December 2019 to look at Fans 44 & 45. These fans are adjacent to one another with one road (Eagle Ridge Road) that forms a loop across the mid-fan regions. These fans were investigated by driving the loop and stopping at culverts to look at the channels and on Fan 45 by taking a walk from a trail head located near the water storage tank to look at the fan apex. The apex for Fan 44 was on private land and could only be observed from the road.

Results:

Maps of the alluvial fans and their outlines are shown in ***Figure 3*** for Indian Hills and ***Figure 4*** for Prison Hill. ***Figure 5*** depicts Fans 44 and 45 from the Genoa area. The base photography for the Indian Hills area were taken on 9 September 1999 and on, or about, 11 November 2018[2]. Following the recommendations of the Alluvial Fan Task Force (2010), the historic aerial photographs available on GoogleEarth were reviewed to look for evidence of flooding over the past 30 years. The earliest aerial photographic coverage for Prison Hill on GoogleEarth was 1990, while the earliest image for Indian Hills is from June 1994. There was no sign of channel avulsion over the past 30 years in either area; however, discoloration of the surface on some of the fans (e.g., 78, 79, & 115) appears to indicate recent alluvial deposition. As will be discussed, the major landform development appears to have occurred in the past (e.g., Quaternary) and many of the current surface features are

2 Base aerial photograph was from the ESRI World Basemap – World Imagery; however, the metadata for the image did not include acquisition date. Searching the historic photographs on GoogleEarth found the closest match to be 11 November 2018. Primary difference being vehicle positions on the highway indicating it might just be a difference in shot frames along flight path. But construction of a new shed on a property near Fan 79 first appeared in August 2017 while a parked trailer was common in the 11 November photograph.

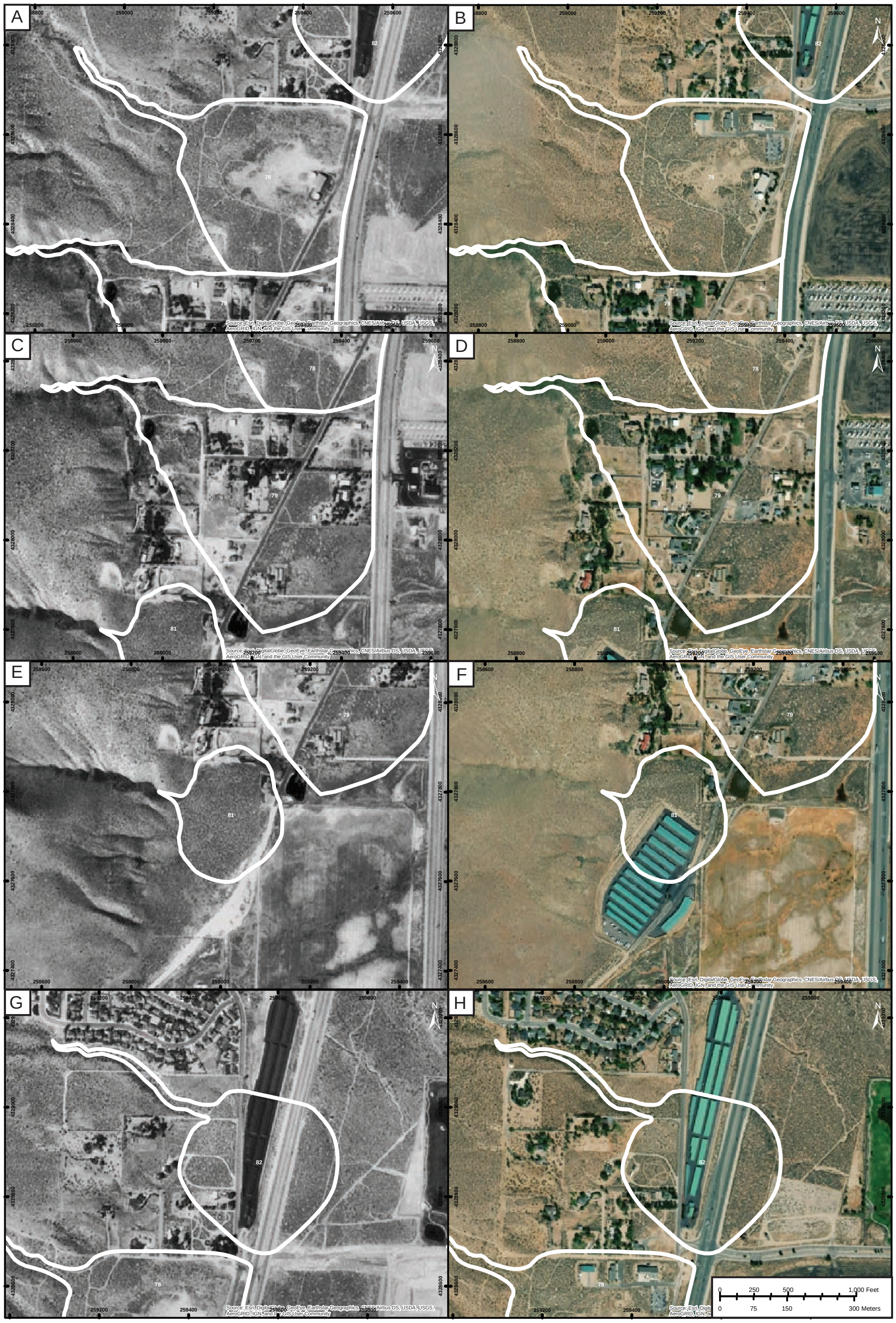


Figure 3. *Indian Hills alluvial fans. Fan 78 A) in 1999 and B) 2018; Fan 79 C) in 1999 and D) in 2018; Fan 81 E) in 1999 and F) in 2018; and Fan 82 G) in 1999 and H) in 2018.*

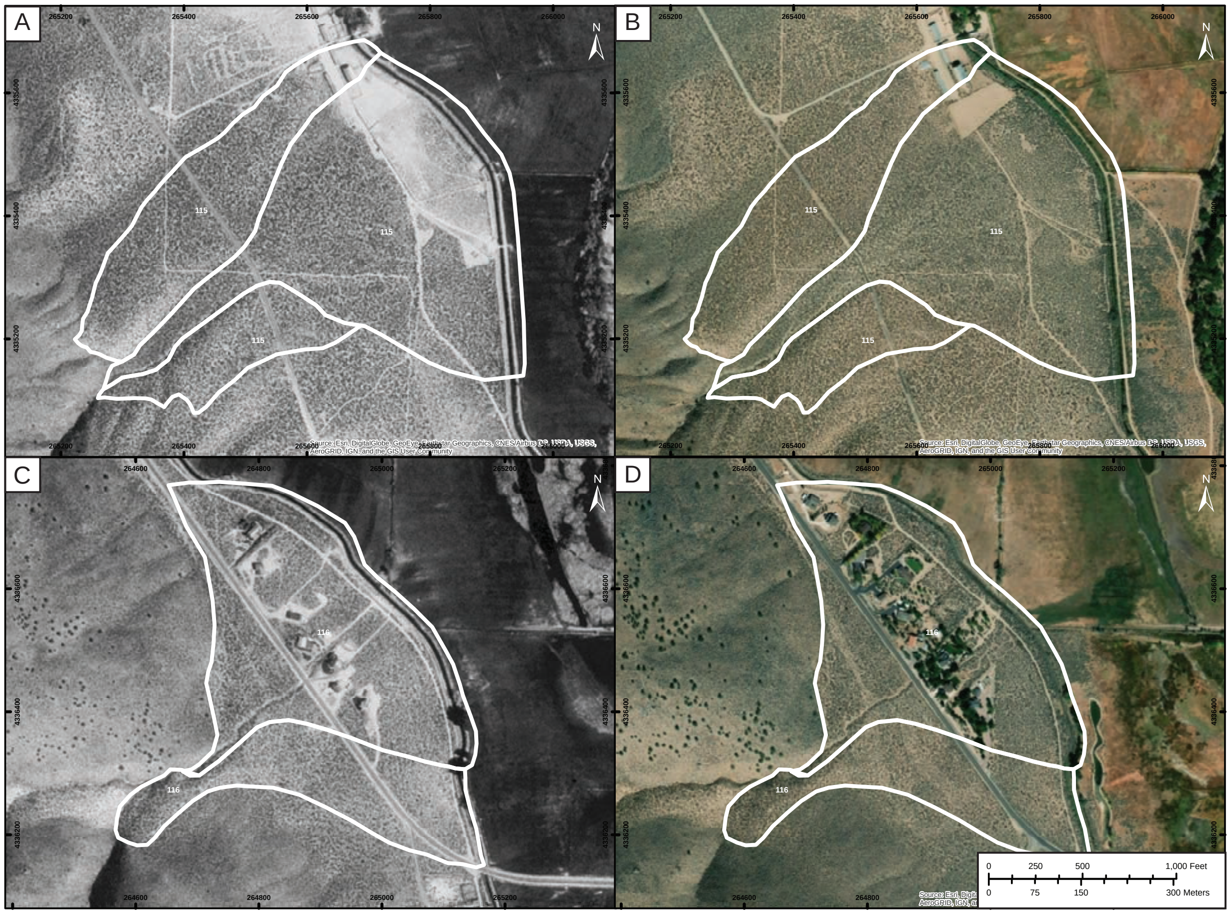


Figure 4. *Prison Hill alluvial fans. Fan 115 A) in 1999 and B) in 2018; and Fan 116 C) in 1999 and D) in 2018.*

"relict". This does not mean the fan surfaces are not active, but were more active under cold, wetter climatic conditions when fan development was more active. Note, during the second site visit there were considerable signs of sediment transport along the road side and dirt trails. This visit occurred shortly after a weekend snow/rain event with no significant flooding, indicating there is considerable transport even during "normal" precipitation events. ***Figure 6*** shows sediment deposited on Carson River Road where it crosses Fan 116 following a flood in 2014. The road flooding occurred after the culvert became blocked by debris and resulted in the deposition of 1 – 2 ft of sandy sediment (photograph provided by R. Fellows, Carson County). As will be discussed, even though the primary landform development may have occurred in the past under different climatic conditions, loose sediment with patchy arid vegetation that is subjected to periodic and intense rainfall (and/or snow melt) events is susceptible to particle transport leading to localized erosion and deposition. Such transport may or may not be visible on the aerial photography.

Indian Hills

Fans 78 – 79 and 81 – 82 are located along the east face of Indian Hills in the Carson River Valley (***Figure 1***). The lobate portion of these fans spread out across map unit *Pediment and*

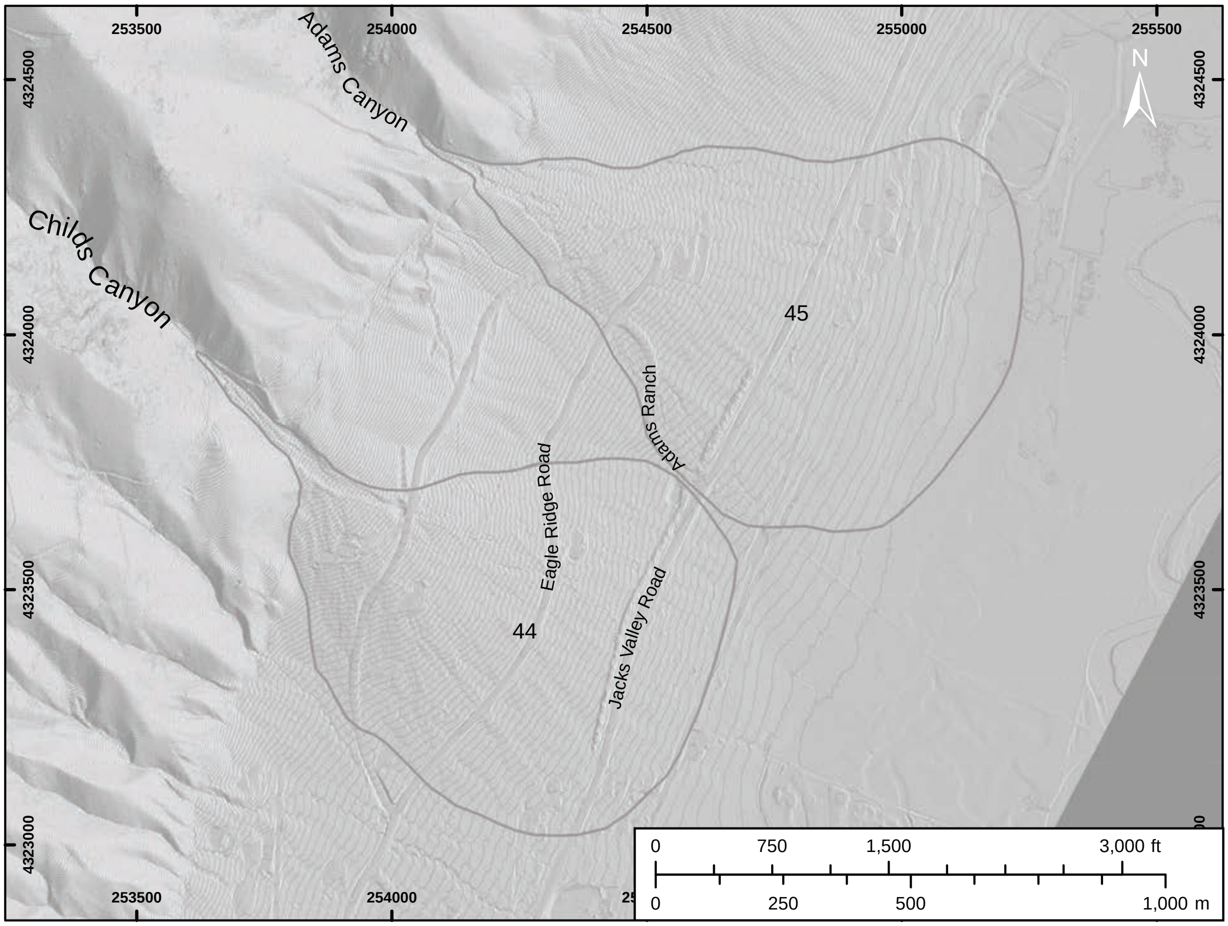


Figure 5. *Outline of Fans 44 and 45 near Genoa, NV with 1 m (3.3 ft) contours generated from the LiDAR data.*

Alluvial Fan Deposits (Qpa) of Pease (1980; ***Figure 7a***). This unit is composed of granular sand and gravel that have spread laterally forming a large coalescent fan apron that extends into the Carson River Valley. Indian Hills is largely composed of *Tertiary to Quaternary age pediment deposits* (QTg) consisting of sand and gravel derived from Tertiary metavolcanics and metasediments. Near the apex of Fans 79 and 81 are outcrops of *Crataceous granodiroite* (Kgd) and *Triassic metavolcanics* (TRmu) rocks.

<u>*Fan 78*</u>

Fan 78 is located west of Highway 395 and bisected by Hobo Hot Springs Road. The US Forest Service Plymouth Interagency Work Center is located along the north side of the fan and east of the fan apex. The site map shown in ***Figure 8*** shows a broad fan head fed by a narrow stream valley that is deeply incised into Quaternary alluvium (***Figure 7a***). The fan covers 137,816 m^2 (34.1 acres) and is part of an alluvial fan complex that extends from the foot of the Indian Hills (***Table 2; Figure 3***). Fan 78 shares a common boundary with Fan 79 to the south.

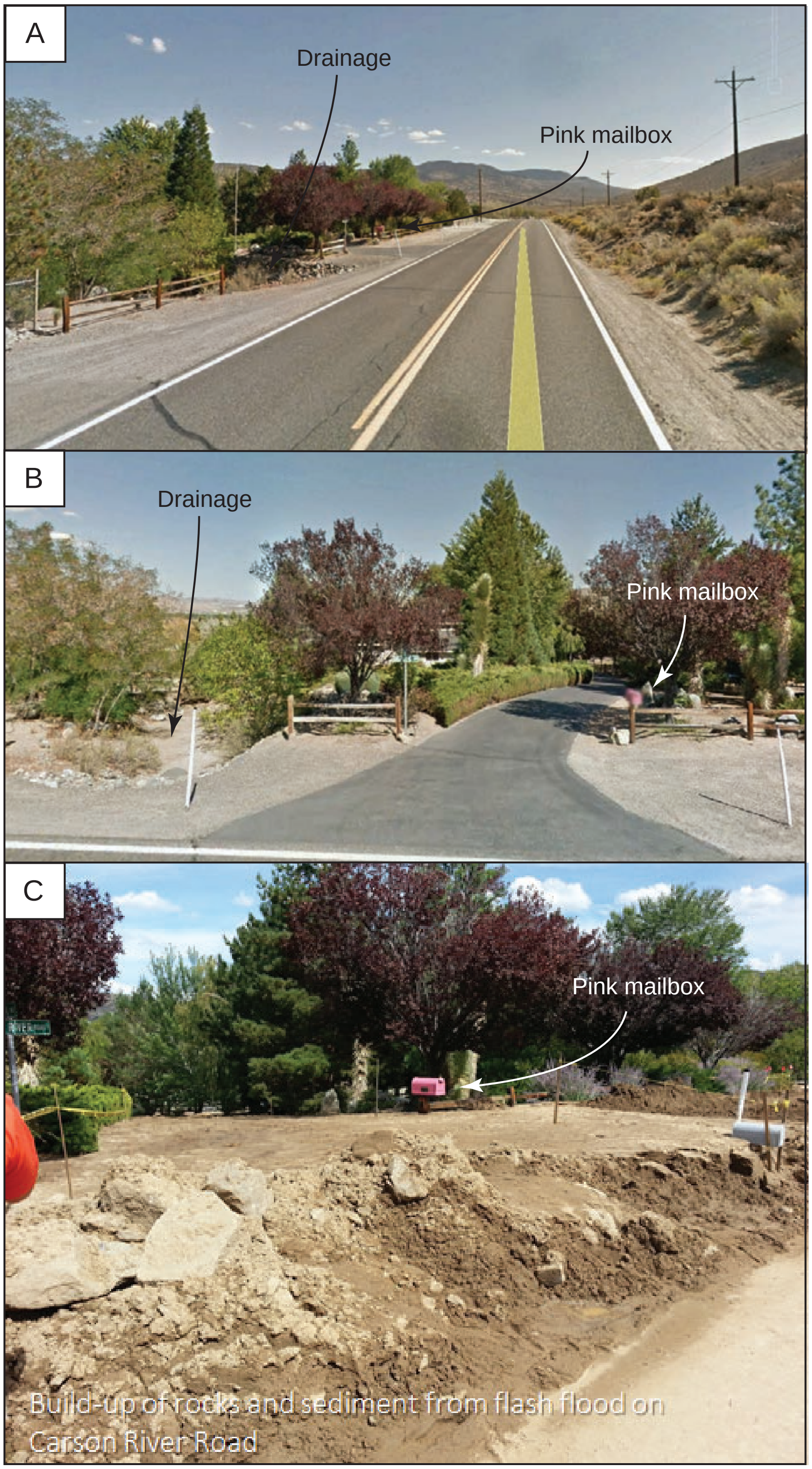


Figure 6. *Sedimentation over Carson River Road on Fan 116 in 2014. General location shown from screen grabs taken from GoogleEarth Street View shown in A & B. Pink mailbox provides general reference. C) Thick sediment deposits cover road and driveway (Photograph provided by R. Fellows, Carson City County). Deposit primarily consists of sandy mud transported in the form of either hyperconcentrated flow or low density sediment gravity flow (mudflow).*

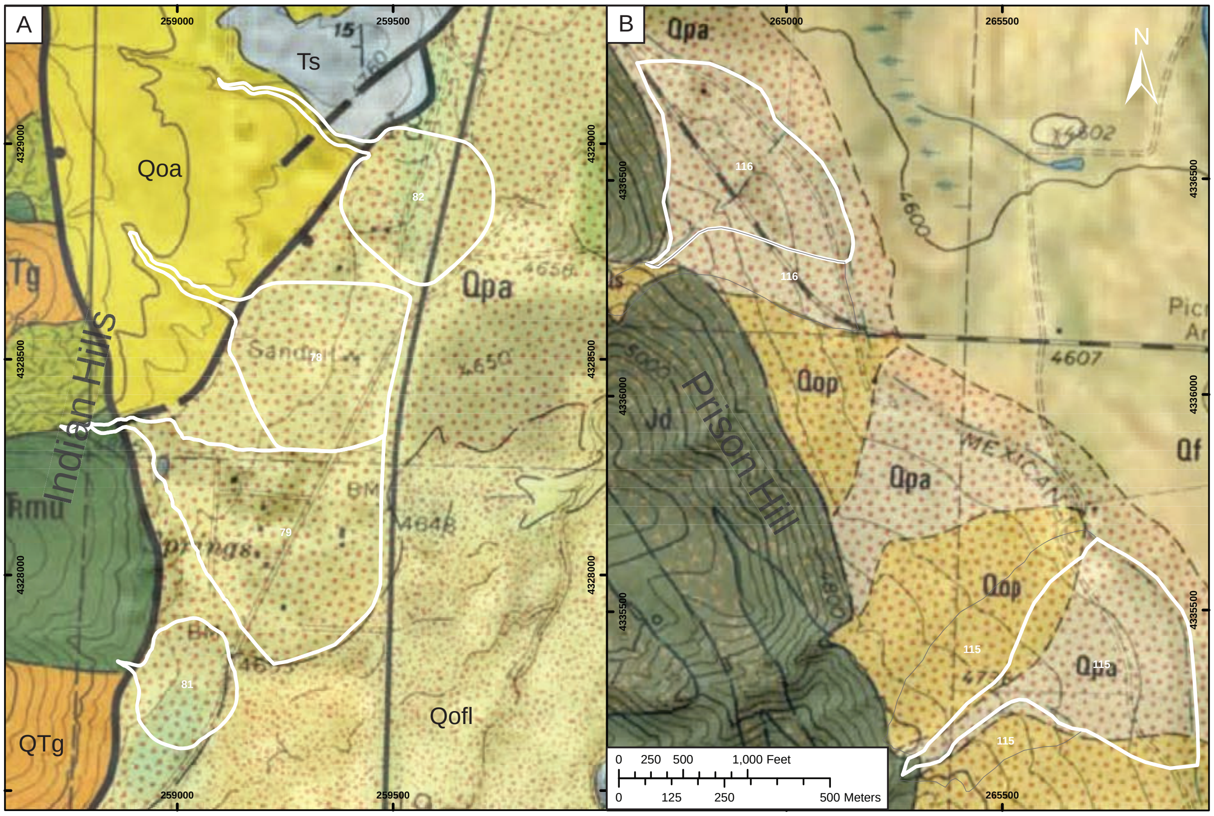


Figure 7. *Geology of the A) Indian Hills (Pease 1980) and B) Prison Hill (Bingler 1977) areas with outlines of select fans. Qoa = Pediment and Alluvial Fan Deposits, Qpa = Pediment and Alluvial Fan Deposits; Qop = Quaternary older alluvial; Qofl = Quaternary older floodplain deposits of the Carson River; Qf = Quaternary floodplain deposits of the Carson River; QTg = Tertiary to Quaternary age Pediment deposits; Ts = Tertiary sediment; Kgd = Crataceous granodiroite; Jd = Jurassic dacite; TRmu = Triassic metavolcanics.*

The "undisturbed" surface of the fan is completely covered with low vegetation (***Figures 9a-b & 10***) with no channels apparent in the LiDAR imagery (***Figure 8***); however, during the site walk small patches of sand deposits were observed (***Figure 9c-f***). The surface of the fan is relatively smooth with low relief, except for a large excavation in the center of the fan and a second excavation along the southern boundary. The surface of the fan slopes away from the topographic apex at about 6 - 8°. A well-developed incised channel fed by a narrow gulley on the side of Indian Hills was observed south of the main feeder channel to Fan 78 (***Figures 8 & 10***). This channel runs along the western and southern edge of the fan and discharges to a zone in between Fans 78 – 79. Surface material was largely composed of sand below a litter of thin organic debris. The exceptions are sand pockets composed of loose sand with no vegetation that appear to be "recent" alluvial deposits. Weathered, angular cobbles and small boulders are also scattered about the surface (***Figure 11***).

Based on the LiDAR mapping, there are two channels located near the topographic apex of the fan: 1) running along the north edge of the fan is a channel that is 0.9 m (2.9 ft) deep. During the site visit the feature appears to be associated with an eroded gravel road; and

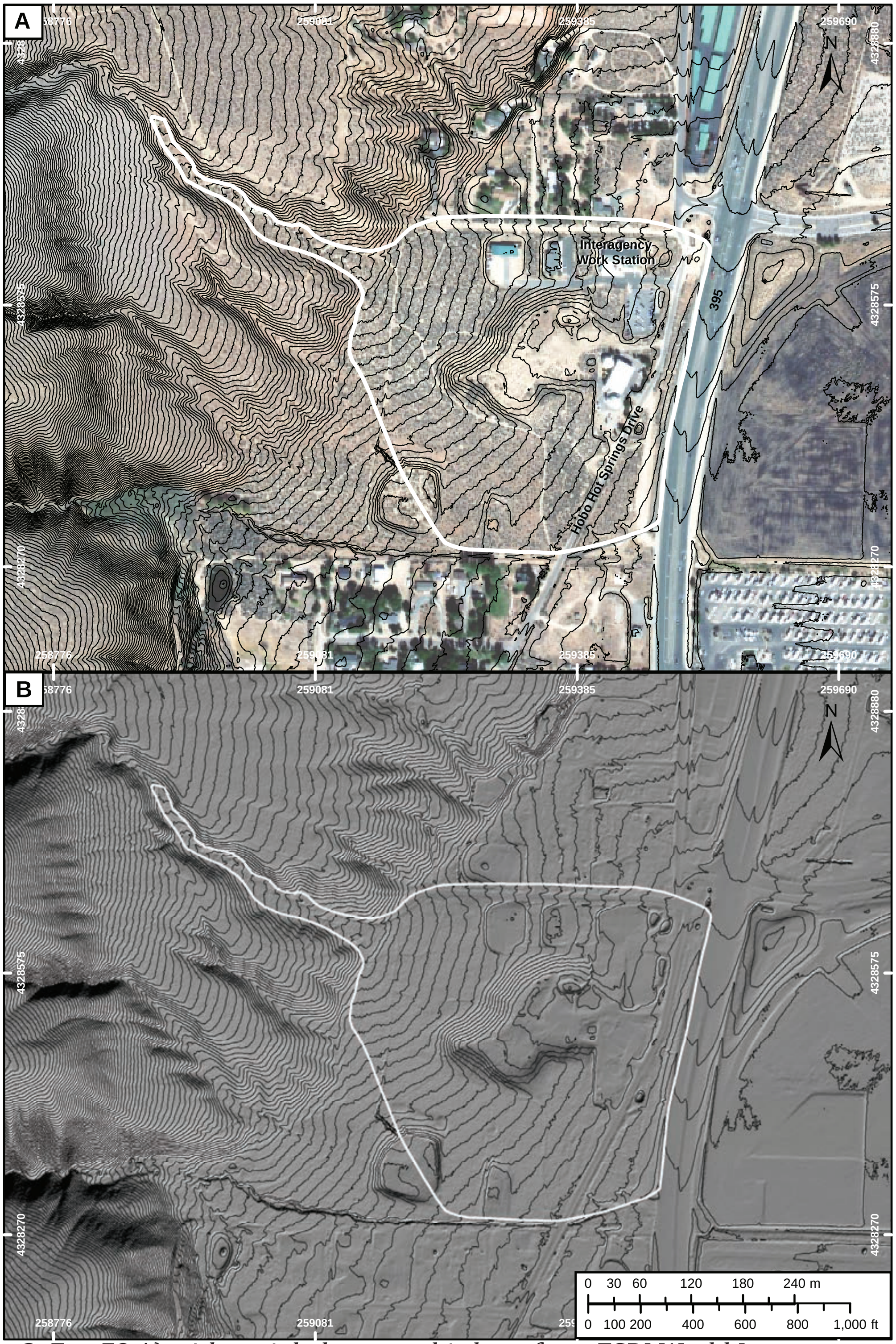


Figure 8. *Fan 78 A) with aerial photographic base from ESRI World Imagery sourced by Digital Globe, and B) Hillshade elevation model generated in Quick Terrain Modeler. Both images show 1 m contours generated from the LiDAR imagery in Quick Terrain Modeler.*

***Table 2.** Alluvial fan summary*

	Area						Consequences of avulsion		
Fan	(cu. m)	Acre	Cultural modification*	Urbanization	Channelization	Likelihood of avulsion	Risk	Farm/ household	Commercial
44	501,041	123.8	M	M	Well-developed fan with active braided channels covering the norther third of the fan. Southern 2/3rds of the fan covered by older, smoothed channels and bar deposits. Smoothing indicates relative inactivity. Fan has experienced significant development over the past 20 yrs. Well-developed fan with active braided channels covering the norther third of the fan. Southern 2/3rds of the fan covered by older, smoothed channels and bar deposits. Smoothing indicates relative inactivity. Fan has experienced significant development over the past 20 yrs.	MH	M-H	X	
45	568586	140.5	M	M	Well-developed fan with active braided channels covering the northern and southern margins of the fan. The central and distal portions of the fan are covered by older, smoothed channels and bar deposits. Smoothing indicates relative inactivity. Fan has experienced some development over the past 20 yrs.	MH	M-H	X	
78	137,816	34.1	H	M	Below the fan apex the main channel runs along the northern margin of the fan conveying water through the housing complex. A very broad depression also occurs below the apex that appears to have captured surface flow in recent history conveying water to the large excavation and to the southern margin of the fan. Evidence of sheetflow depsoits on fan surface	M	M-H	X	
79	202,823	50.1	M	M - H	Well-developed primary channel that runs along the northern boundary of the fan. This channel is engineered to convey water off of the fan. A secondary channel near the apex is blocked by a levee or retaining wall on the main channel.	M	H	X	
81	54,140	13.4	H	H	Single incised feeder channel drains valley; channel follows base of mountain slope until it reaches a gentle slope and spreads (active). There is evidence that flows have crested over the channel banks and discharged down the center of the fan. Also, drainage barriers along access roads west of the storage facility has led to discharge and erosion down gradient of the structures.	M-H	L	X	X
82	99,350	24.5	H	H	Well-developed incised channel exits mountain valley then appears to be diverted into engineered channel to cross under roads, highway, and industrial site. Appears to have some minor relict chann+A1els south of the fans apex.	L	H	X	X
115	171,496	42.4	L	L	Fan has a narrow, shallow channel that extends about 240 m from the topographic apex to the hydrologic apex. Surface is generally smooth (low relief); There appears to be photographic evidence that the flow occurred outside of the main channel sometime after April 2014. Several confined "lobes" of light coloration on the April 2015 photograph are suggestive of thin, recent deposition. Sheetflow sands on surface below hydrologic apex	M-H	M-H	X	
116	139,539	34.5	M	M-H	Well-developed incised channel exits mountain valley and crosses 2/3rds of fan beforel it discharges onto fan surface.	M-H	M-H	X	

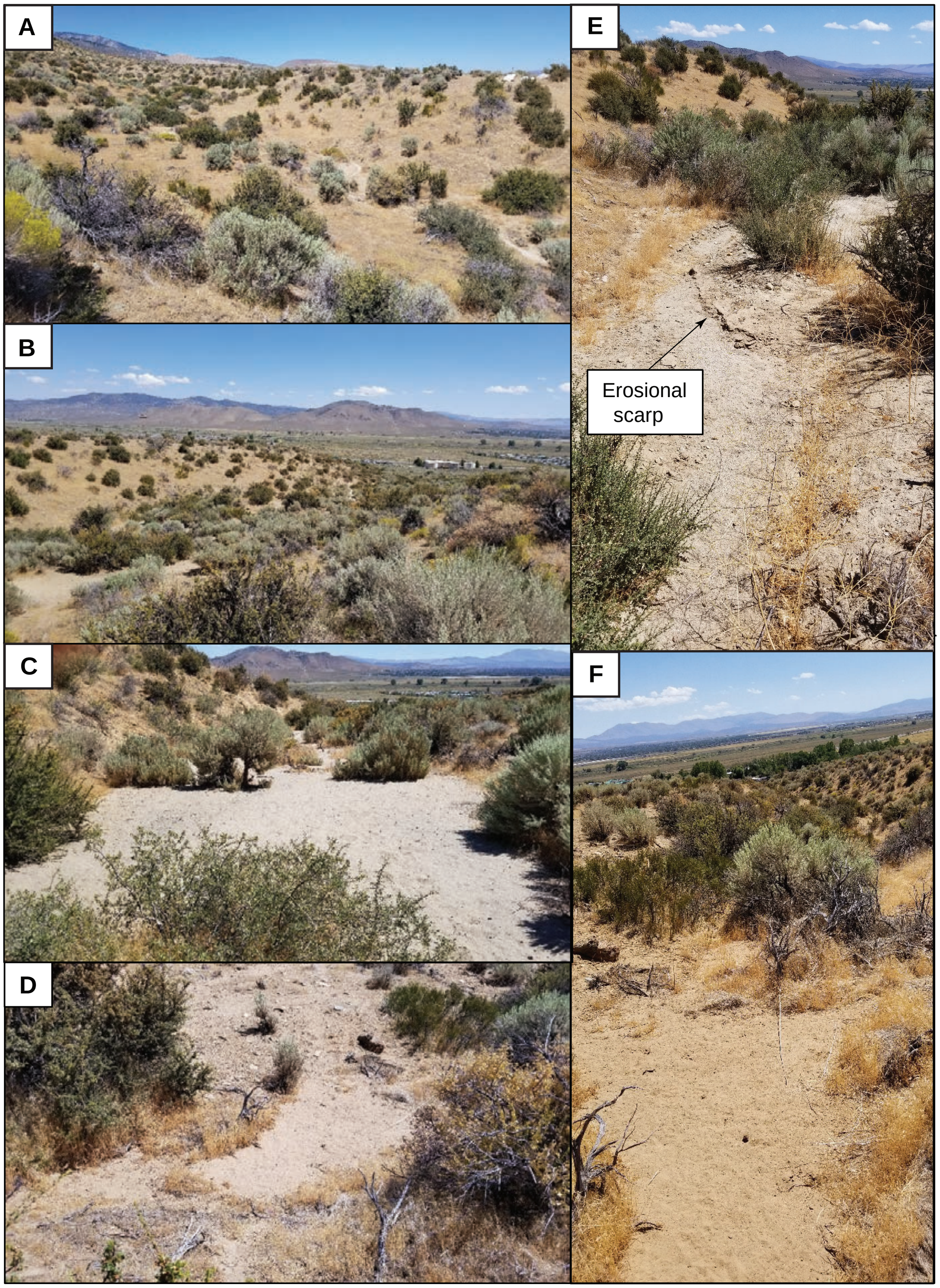


Figure 9. *Photographs from main feeder channel to Fan 78. Underfit stream bed located in large incised channel. A) Looking upstream from the southern bank and (B) downstream. (C - F) Recent sandy alluvium in center of channel represents modern deposition. E) Shallow channelization can be observed in the deposits. Channelization disappears below the topographic apex indicating that flow diverges as it exits the channel confines.*

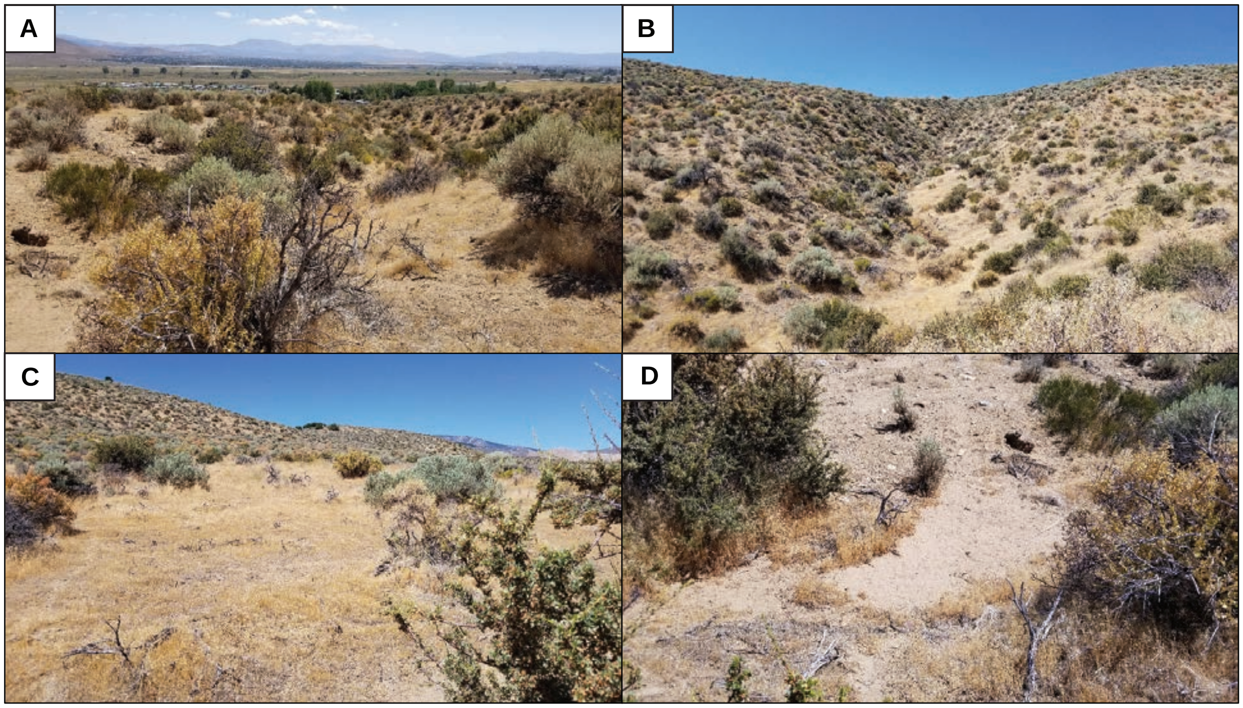


Figure 10. *View of Fan 78 at Site 1. Incised channel shown in A & B is fed by gully on southwest margin of fan that feeds zone between Fans 78 & 79. Channel in incised into stable fan surface (C) although small pockets of sand is observed filling topographic lows (D). These sand deposits appear to represent deposition from sheet flow.*

2) a meandering channel that follows the northern portion of the channel that extends about 150 m (500 ft) from the topographic apex then meanders across the middle of the channel about 50 m (164 ft) from the apex. The channel looked to be about 3.5 – 4 m (11.5 – 13.1 ft) wide and 4 m deep (13.3 ft) from the LiDAR data. The active portion of the channel is underfit (e.g., too small to account for the size of the channel) with respect to the overall size of the channel, indicating that the channel morphology is a relict feature from times of higher flow conditions (***Figure 11a-b***). There are modern sand deposits that form a ribbon of clean sand along the floor of the channel (***Figure 11c-d***). The ribbon locally contains broad patches of thin, loose sand deposits, and in other locations where constrained, there is evidence of localized erosion from channelized flow (***Figure 11e***).

Below the topographic apex, the meandering feeder channel discharges towards a very shallow (~ 0.1 m [0.3 ft]) and broad depression (2.5 – 3 m [8.2 – 9.8 ft]) that cuts across the fan and deflects to the south. About 100 m (~330 ft) from the topographic apex, drainage from the "channel" appears to be captured and diverted to large excavation. Lower down gradient an excavated trench about 2.5 – 3 m (8.2 – 9.8 m) deep likely captures surface flow. Aerial photographs from April 2015 and August 2017 photographs exhibit zones with lighter reflectance tones than neighboring areas (***Figure 12***). The sand patches described above fall within these areas and it appears that the lighter zones represent areas of recent sand deposition from sheetflow events.

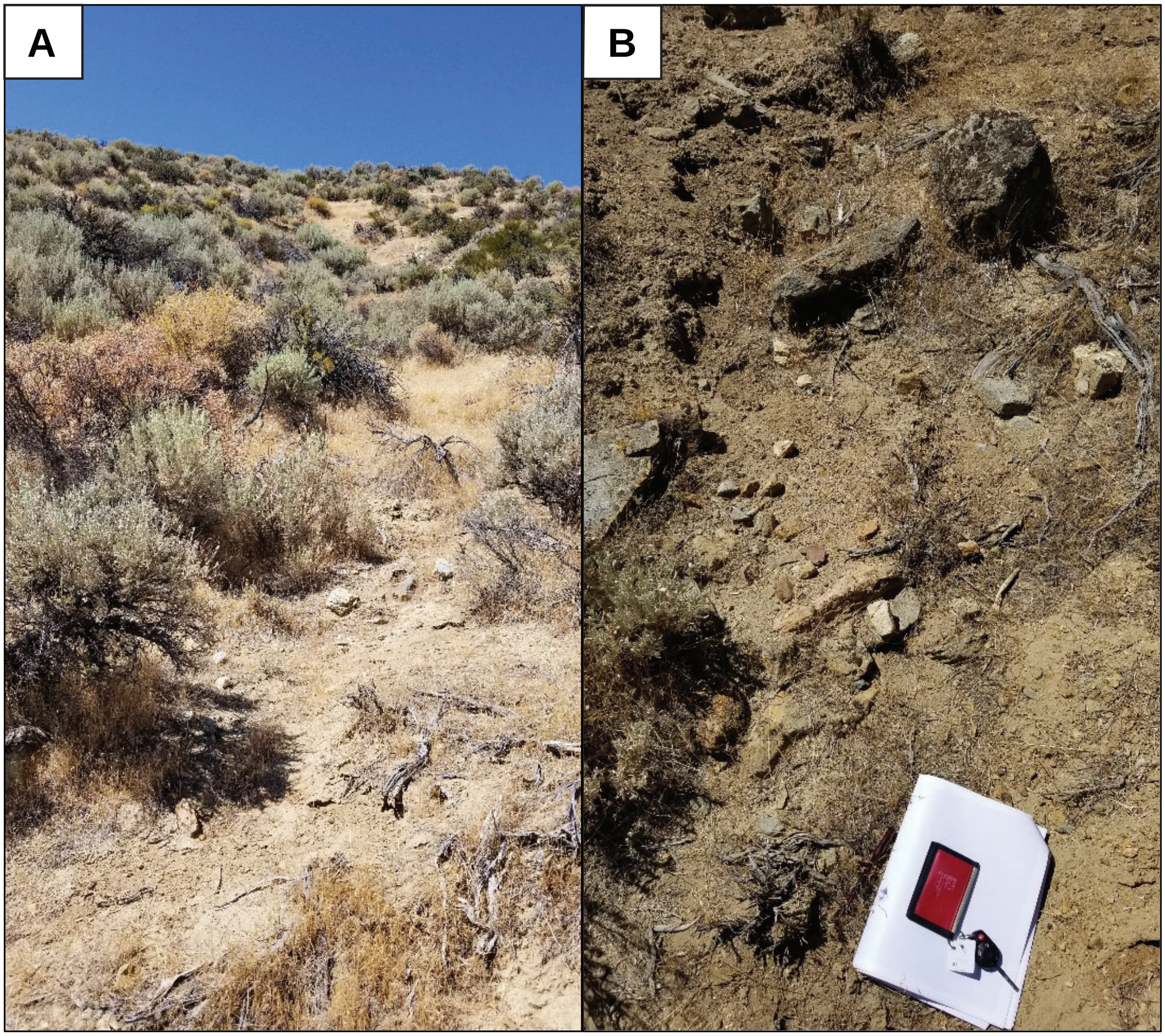


Figure 11. *Surface materials on Fan. A) Scattered angular to subangular boulders in a sandy matrix and B) close-up view of the angular characteristic of boulders and cobbles.*

Modern deposition in the main channel appears to be characterized by sand ribbons and sandy patches below the fan apex. Flow outside of the channel results in thin sheets of sand that fills small surface depressions (sheetflow deposits). The larger clasts (or stones) on the fan surface (cobbles/boulders) generally appear weathered, angular, and are much larger than the sands that cover the majority of the surface (***Figure 11***). Modern flows depositing the sand do not have the competence to transport these larger particles and the particle size distribution is not what would be expected from a flow capable of transporting boulders and cobbles. The interpretation is that these larger particles are relict from a colder, wetter climate when fan building was more prevalent. Because of the angularity and distance transported downslope, these cobbles/boulders are believed to represent old deposits that have been exposed to weathering for a considerable time (1000s of years).

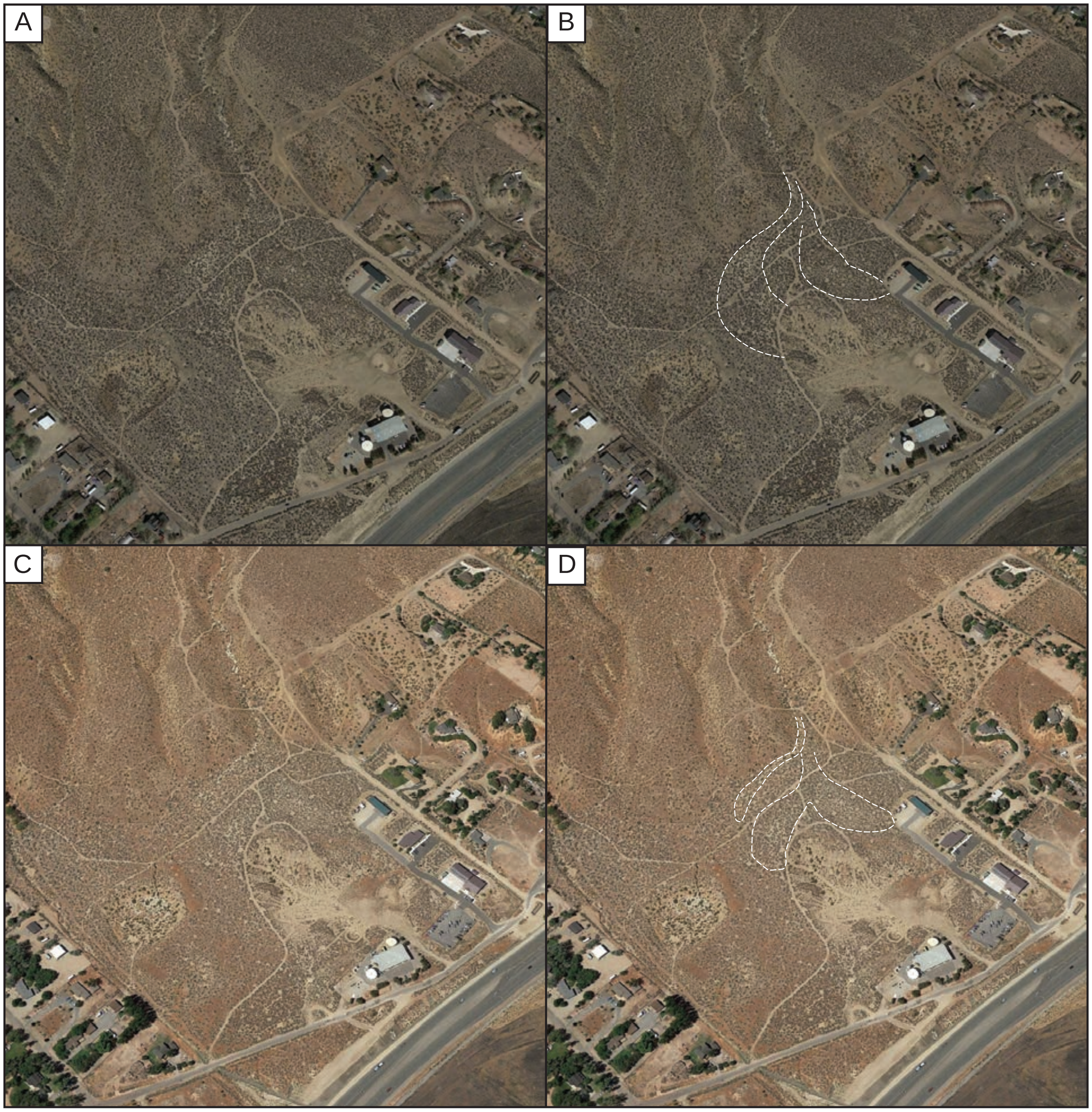


Figure 12. *Oblique aerial photographs of Fan 78 from GoogleEarth. Photos A) and B) are from April 2015, with B showing interpreted discoloration caused by deposition from surface flows. Photograph C) was taken in August 2017 with D) showing outline of interpreted recent deposition.*

Fan 79

Fan 79 located west of Highway 395 is the largest fan studied in the Indian Hills area covering 202,823 m^2 (50.1 acres; ***Table 2; Figure 13***). Hobo Hot Springs Road crosses the lower mid-fan region and the surface west of the road is highly modified with numerous

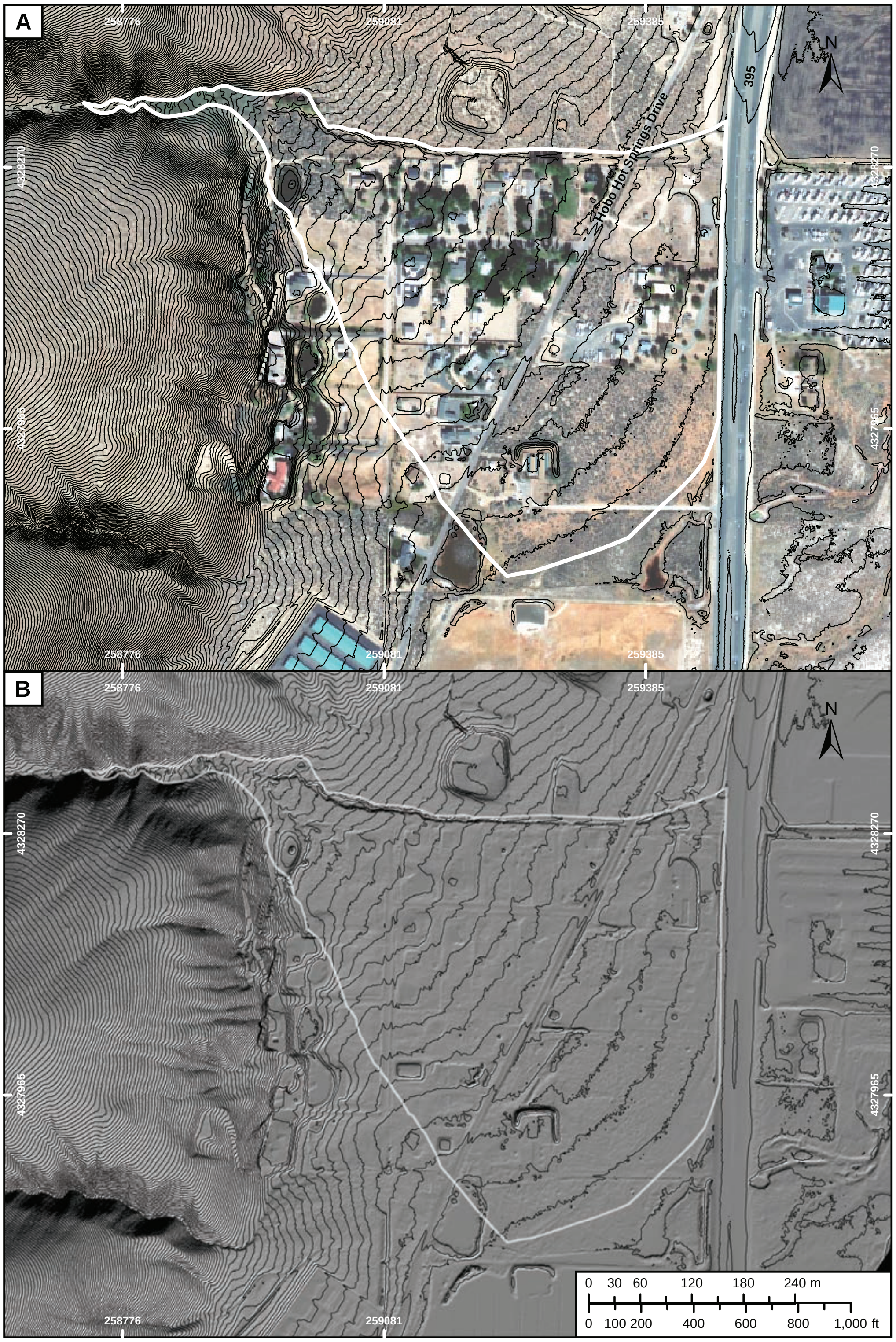


Figure 13. *Fan 79. A) With aerial photograph base from the ESRI World Imagery coverage sourced by Digital Globe. B) Hillshade elevation model generated in Quick Terrain Modeler. Both images show 1-m contours generated by Quick Terrain Modeler.*

Figure 14. *Photograph from intersection of Powers Ave and Washoe Springs Rd looking to the west-northwest on Fan 79. Field is well manicured with gently rolling surface. There is no indication of surface flow across field.*

home plots. Washoe Springs Road was visited during the site visit but access to the fan was limited by fences and gates on the road leading up to private properties. ***Figure 14*** was taken from Washoe Springs Road looking in the direction of the fan apex and reveals a gently rolling topography and well-manicured field with no apparent indication of recent alluvial activity.

The northern edge of the fan is delineated by a man-made, gravel lined ditch (***Figure 15***). West of Hobo Hot Springs Road the ditch is slightly overgrown while east of the road the ditch is clear of vegetation. The southern boundary of the fan coincides with a wetland area along its border with Fan 81 (***Figure 16***). There are several ponds located along the range front associated with darker, wetter zones between Fans 79 and 81 (***Figure 13a***). This zone appears to feed a wet area that exists along the northern border of Fan 81. Nearing Hobo Hot Springs Road this wetland zone shares a common border between Fans 79 and 81. Given the name of the road and presence of what appears to be perennial ponds and wetlands, it is inferred that this wet zone is fed by a series of springs along the range front.

The source of the fan is a valley cut along the boundary between *Cretaceous granodiorite* and *Triassic metavolcanics* (***Figure 7a***). Little of the surface is undisturbed as streets and home lots cover more than half of the fan (***Figure 13***). What "undisturbed" surface remains is covered with low vegetation. There are no apparent breaks in the natural surface morphology that would indicate modern channelization. The feeder channel is not well-defined upgradient of the fan apex, likely indicating that the stream channel spans the width of the narrow valley. From the LiDAR data, the feeder channel bifurcates into two channels at fan apex. The main channel discharges into the engineered channel along northern edge of fan. The initial 60 m (~197 ft) exhibits an incised meandering channel pattern that is about 8 m (26 ft) wide and 1.2 m (3.9 ft) deep. The next ~50 m (164 ft) also meanders within a 13 m (43 ft) wide and 1.8 m (5.9 ft) deep channel. The lower segment

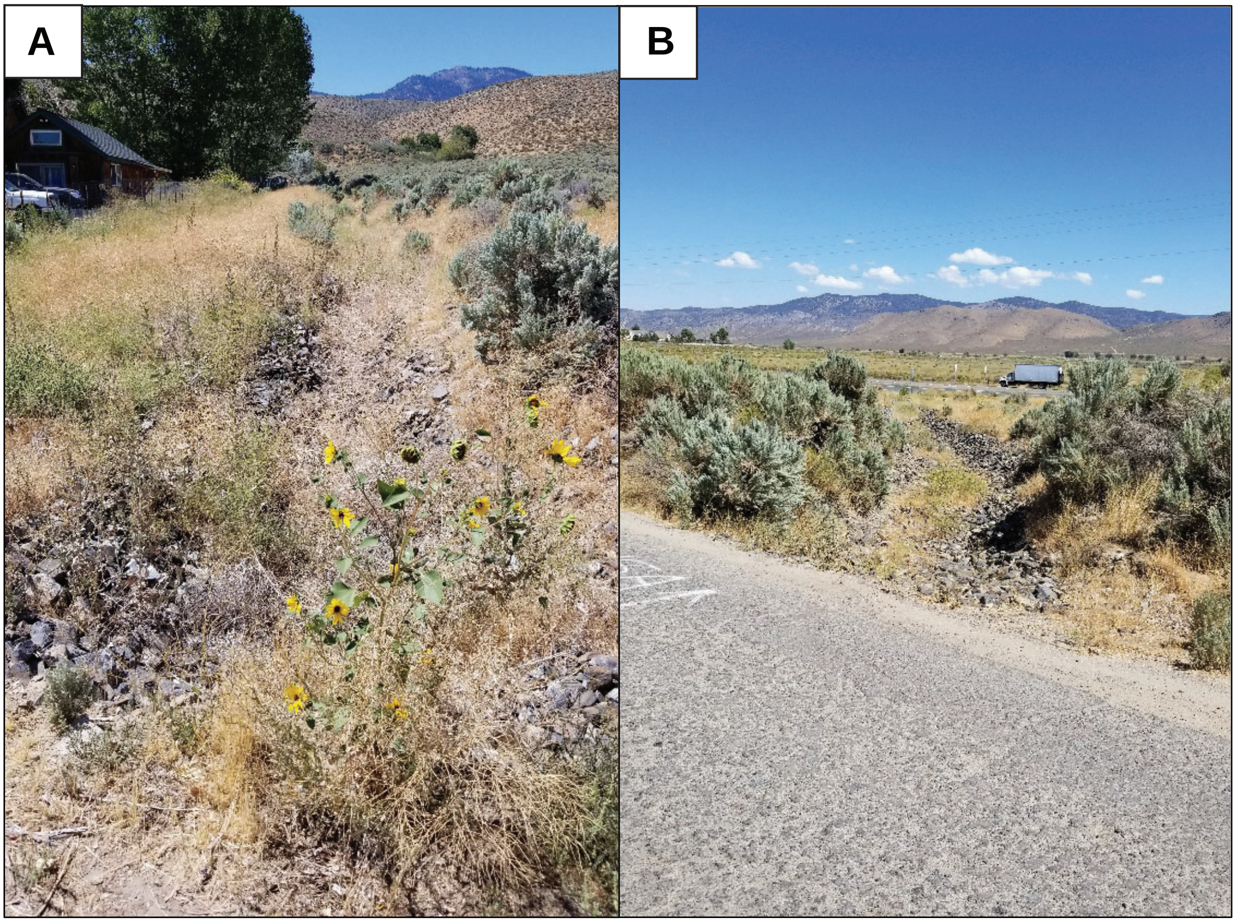


Figure 15. *Gravel-lined drainage ditch along north side of fan where ditch crossed Hobo Hot Springs Road. (A) Looking to the west and (B) looking to the east.*

of the channel is straight and becomes less incised to the east. The channel is roughly 4 m (13.1 ft) wide and about 1 m (3.3 ft) deep with a berm along the south bank to protect the houses from flooding. The ditch feeds a culvert that directs water under Highway 395 into the Carson River floodplain.

From the LiDAR data there appears to be an engineered barrier preventing flow from the main active channel to a second channel that appears to be a remnant of a natural channel. Below the apex this channel forms a broad (19 m [62 ft]), shallow (< 1 m [3.3 ft]) swale that extends 60 – 80 m (197 – 262 ft) to the southeast of the fan apex. Based on the field visit, this channel appears inactive. If the barrier were to breach, the hydrologic apex would be 100 to 120 m (328 – 394 ft) downgradient. Sheetflow would cover much of the downgradient slopes, which dip less than 6° to the east (***Figure 2***).

<u>*Fan 81*</u>

Fan 81 is the smallest fan in this study (54,140 m^2 or 13.4 acres) and southernmost fan studied in the Indian Hills area (***Table 2***). The fan is circular in plan view with a small feeder channel that flows out of an area of *Triassic metavolcanics* (***Figure 7***). The fan is

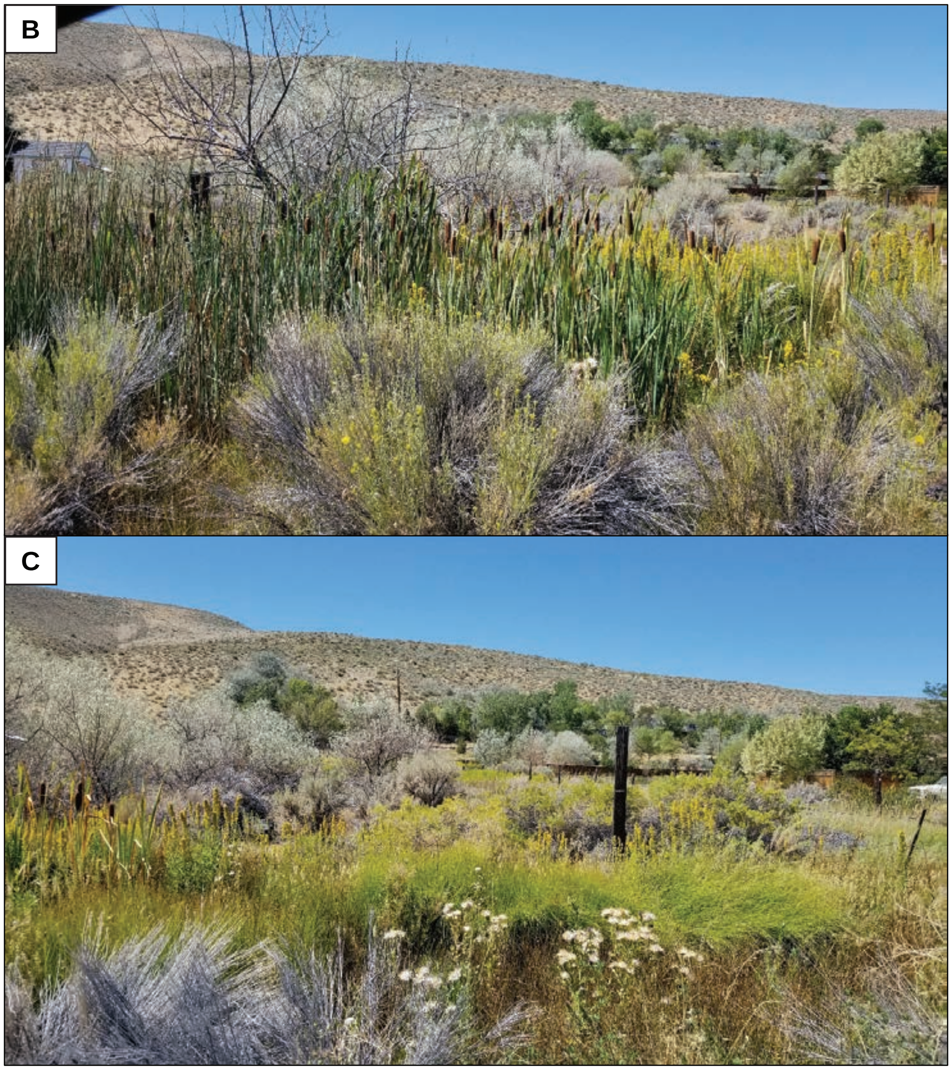


Figure 16. *Wetland vegetation along the boundary of Fans 79 and 81.*

located west of Highway 395 and has undergone significant modification with the building of the Hobo Self Storage facility (***Figure 17***). Away from the storage facility the fan surface is generally smooth, with low relief and a shrub vegetation cover (***Figure 18***). In 1999, the fan was relatively undeveloped, except for a farmhouse in the northwest corner. The fan and slopes are between 4° and 9° (***Figure 2a***) and the fan is fed by a single feeder channel constrained within the walls of the bedrock valley. Just above the topographic apex, the feeder channel is 7 m (23 ft) wide and 1.6 m (5.3 ft) deep. Below the topographic apex, most of the drainage is diverted into a channel that runs along the northern edge of the fan. This drainage wraps around to the east and feeds a low laying, active alluvial surface adjacent to the farm. Along the berm just north of the storage facility surface material is characterized by medium to coarse sand with angular granules to cobbles. There is also a large boulder on the fan surface north of the facility that was likely excavated during construction. This

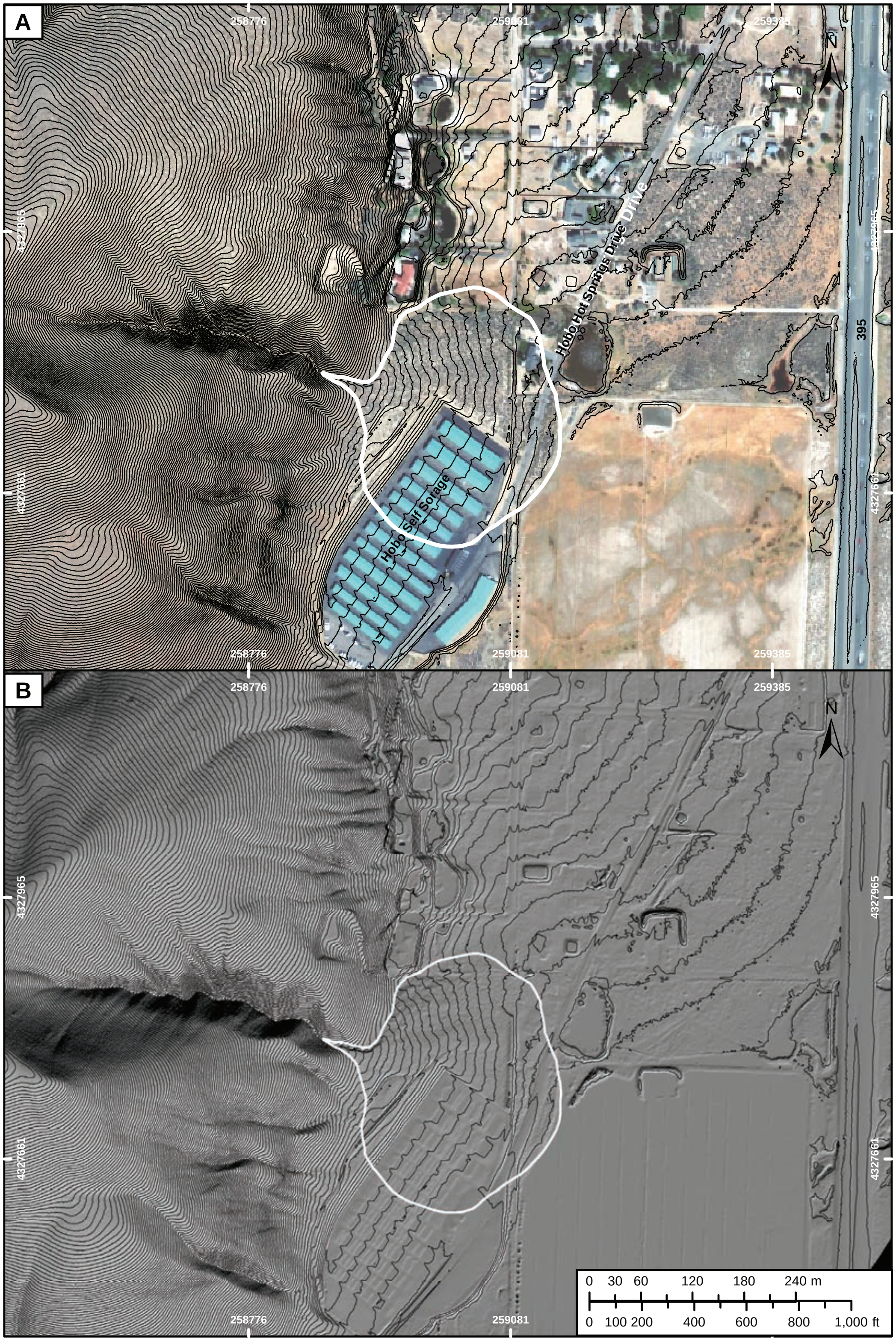


Figure 17. *Fan 81. A) With aerial photograph base from the ESRI World Imagery coverage sourced by Digital Globe. B) Hillshade elevation model generated in Quick Terrain Modeler. Both images show 1-m contours generated by Quick Terrain Modeler.*

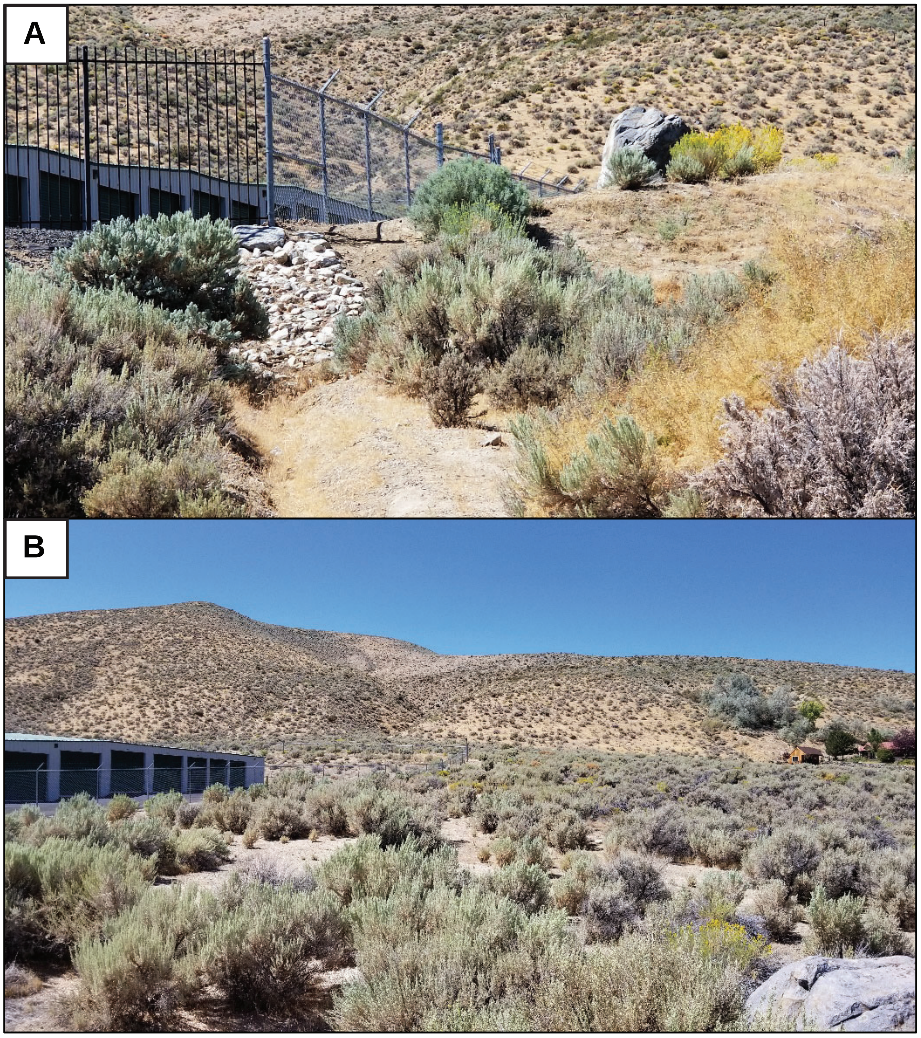


Figure 18. *Fan 81 along north edge of Hobo Self Storage. (A) Gravel lined drainage feature at northeast edge of pavement. (B) Gently undulating mid fan region and (C) medium to coarse sand with angular granules and pebbles in mid fan region.*

boulder is much larger than any other clast observed. There was no evidence of modern debris flow observed.

The active feeder channel to the fan turns sharply to the north at the fan apex and follows the base of the mountain front, ultimately discharging into a low area between Fans 79 and 81(***Figure 19***). This zone extends from the mountain front to the east side of Hobo Hot Springs Drive. Partway along the mountain front is a shallow channel that intersects the main channel at a high angle. This channel cuts across the fan in an east –northeast orientation and represents an area where surface flow has resulted in erosion of the fan surface and is a likely location for channel avulsion.

On the southern half of the fan there is a road and drainage ditch that cut into the slope that capture flow running off of the fan. The ditches feed a small channel at the north side of the self-storage facility that drains to east. This channel is about 2 m (6.6 ft) wide and maybe 0.2 m (0.7 ft) deep. A berm that extends from the northeast corner of the self-storage facility and extends northward towards the farm house is breached where it intersects the channel, presumably to prevent storm water from ponding and flooding (***Figure 20***). The channelization into the slope and human breaching of the levee indicate this portion of the fan is active. There is also a gravel lined drainage ditch on the northeast side of the storage facility deal with surface drainage, but this might just be from water captured on the asphalt.

Figure 19. *Evidence of recent alluvial activity on Fan 81. A) Oblique view looking to the north of a hillshaded relief model. There are two zones (marked active in center of image) where there has been channelization caused by surface flow. The GoogleEarth aerial photograph shown in B) was taken in October 2006. Approximate area of the active zones highlighted in A) are dashed. Fan 82*

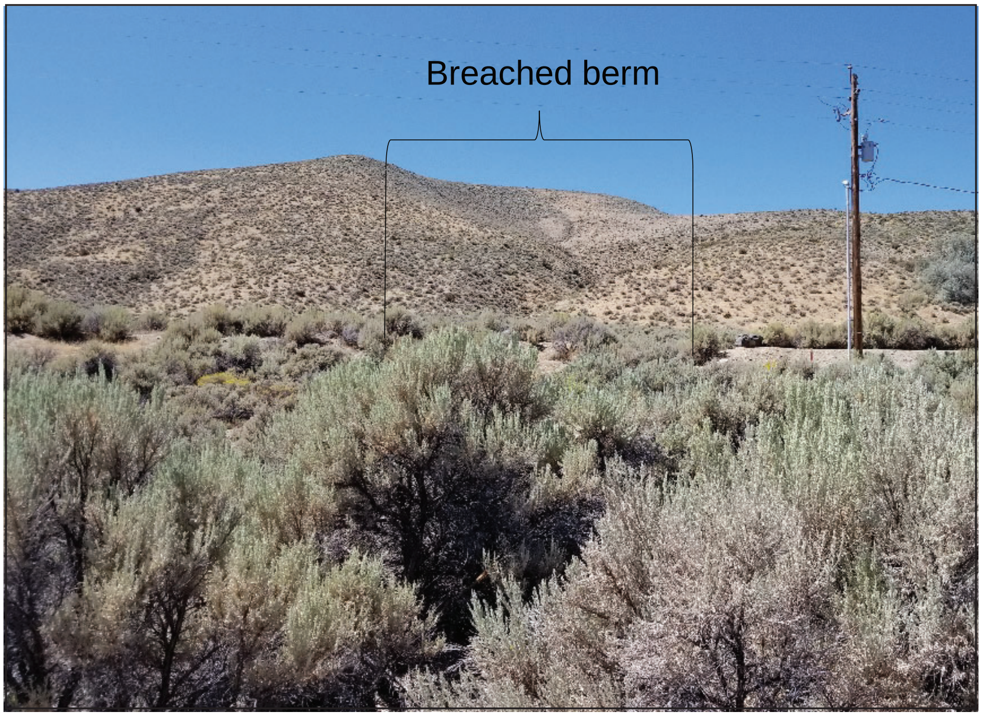


Figure 20. *Breached berm on north side of Hobo Hot Springs Road to accommodate surface flow off of Fan 81.*

<u>*Fan 82*</u>

Fan 82 is the northernmost fan evaluated in the Indian Hills area. The fan is located on the west side of Highway 395 and is nearly bisected by the Carson Valley/Tahoe Self Storage facility on Plymouth Road (***Figure 21***). The fan is fed by a long, deeply incised feeder channel that cuts into ancient terrace deposits mapped as *Older Quaternary alluvium* (Qoa) and *Tertiary sediment* (Ts; Pease 1980; ***Figure 7a***). The feeder channel is bracketed by these terrace deposits with little or no availability for channel avulsion. The topographic apex is located along a fault mapped at the edge of these deposits. East of the fault trace, the fan is generally circular in planview. The Carson Valley/Tahoe Self Storage facility and Highway 395 cover a significant portion of the fan, cutting across its mid-fan region in a roughly north – south orientation. There are also a few houses located on the southwestern portion of the fan. Only the upper portion of the fan near the topographic apex and the distal portion east of the highway are relatively undisturbed. There also appears to be minor relict drainage channels within 50 m (~164 ft) of the topographic apex. These channels are wide (10 to 14 m [32.8 – 46 ft]) and shallow (0.15 to 0.25 m [0.5 – 0.8 ft]) with no apparent recent (since engineered channel built) activity. In those areas, the ground is covered by low vegetation. Surface materials are composed of sand and slopes generally fall in the range of 4° – 6°.

The LiDAR data appears to show an engineered channel along the northern edge of the fan but this was not be verified in the field. This ditch is about 2.5 m (8.2 ft) wide and 0.5 m

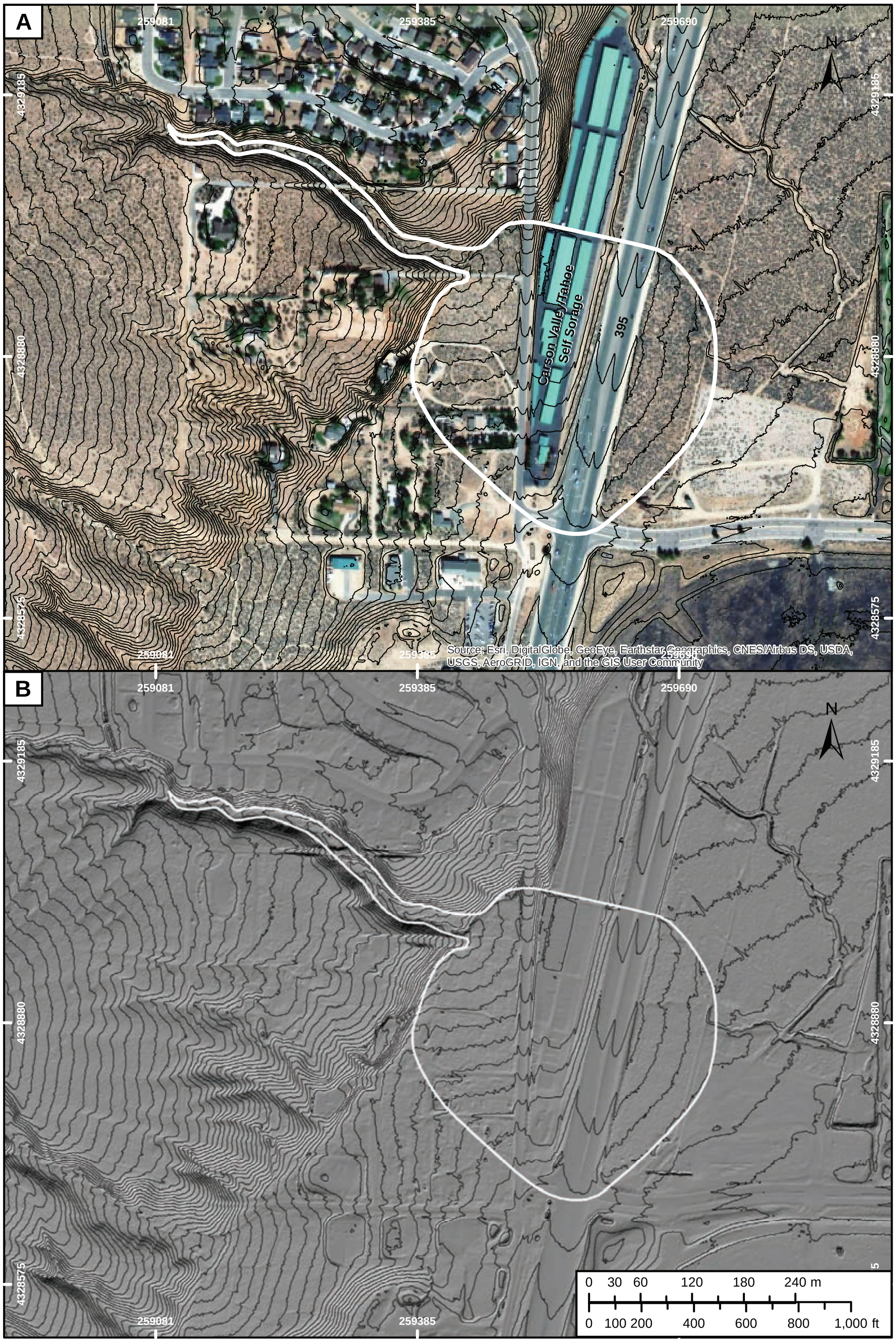


Figure 21. *Fan 82. A) With aerial photograph base from the ESRI World Imagery coverage sourced by Digital Globe. B) Hillshade elevation model generated in Quick Terrain Modeler. Both images show 1-m contours generated by Quick Terrain Modeler.*

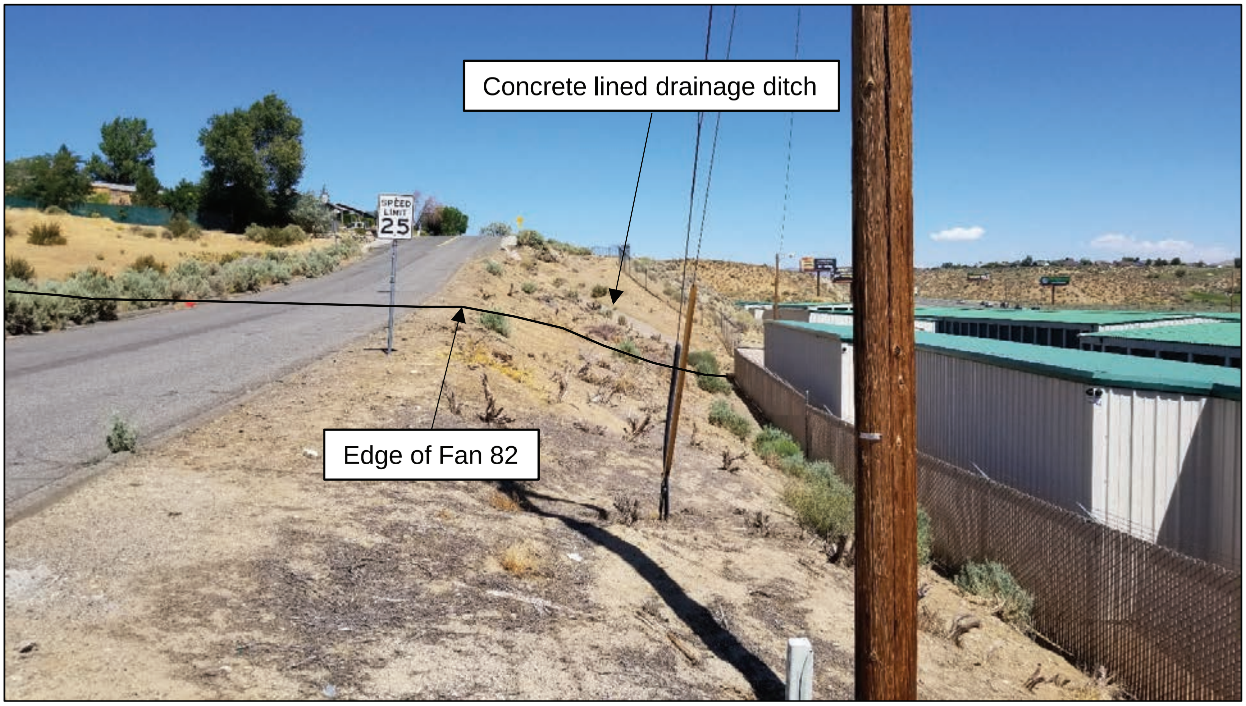


Figure 22. *View of the northern edge of Fan 82 looking north up Plymouth Road. Drainage apparent on LiDAR data is fed by concrete lined ditch that drains Plymouth Road high area north of fan boundary.*

(1.6 ft) deep. Presumably, flow must be directed under Plymouth Drive and the self-storage facility roughly along the boundary line depicted on ***Figure 22***. There is a concrete lined drainage ditch that flows into the area east of Plymouth Road that drains storm water from the bluff north of the site.

Prison Hill

Fans 115 and 116 are located on the east facing slope of Prison Hill and the west bank of the Carson River (***Figure 7b***). Both fans were mapped by Bingler (1977) as P*ediment and Alluvial Fan Deposits* (Qpa) with a general fan shaped outline for Fan 115 and as a fan merging into a coalescent fan apron to the north for Fan 116. These fans originate from mountain valleys that cut into Jurassic aged Dacite to the west and terminate against *Quaternary floodplain deposits of the Carson River* (Qf). Bingler described the composition of the fans as granular, muddy, coarse sand to sandy gravel.

<u>*Fan 115*</u>

Fan 115 is located on Silver Saddle Ranch, which is accessed from Carson River Road (***Figure 23***) and is the southern fan investigated along the eastern face of Prison Hill (***Figure 4***). As mapped, the fan covers 171,496 m^2 (42.4 acres) and is almost completely covered by sage brush that is up to 4 – 5 ft tall (***Figure 24a-b; Table 2***). There appears to be remnants of an older alluvial fan surface that Fan 115 is incised into, forming a nested fan

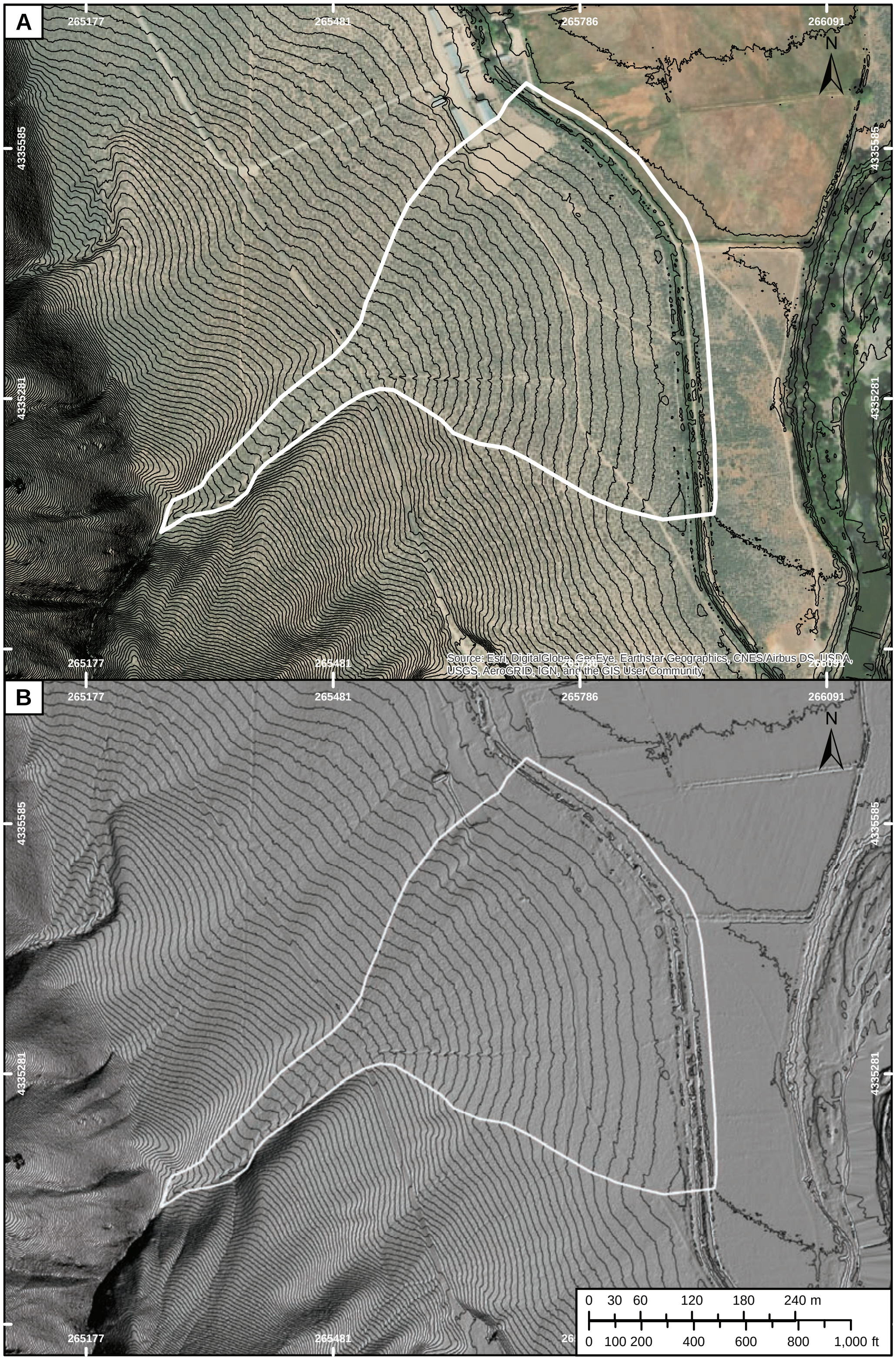


Figure 23. *Fan 115. A) With aerial photograph base from the ESRI World Imagery coverage sourced by Digital Globe. B) Hillshade elevation model generated in Quick Terrain Modeler. Both images show 1-m contours generated by Quick Terrain Modeler.*

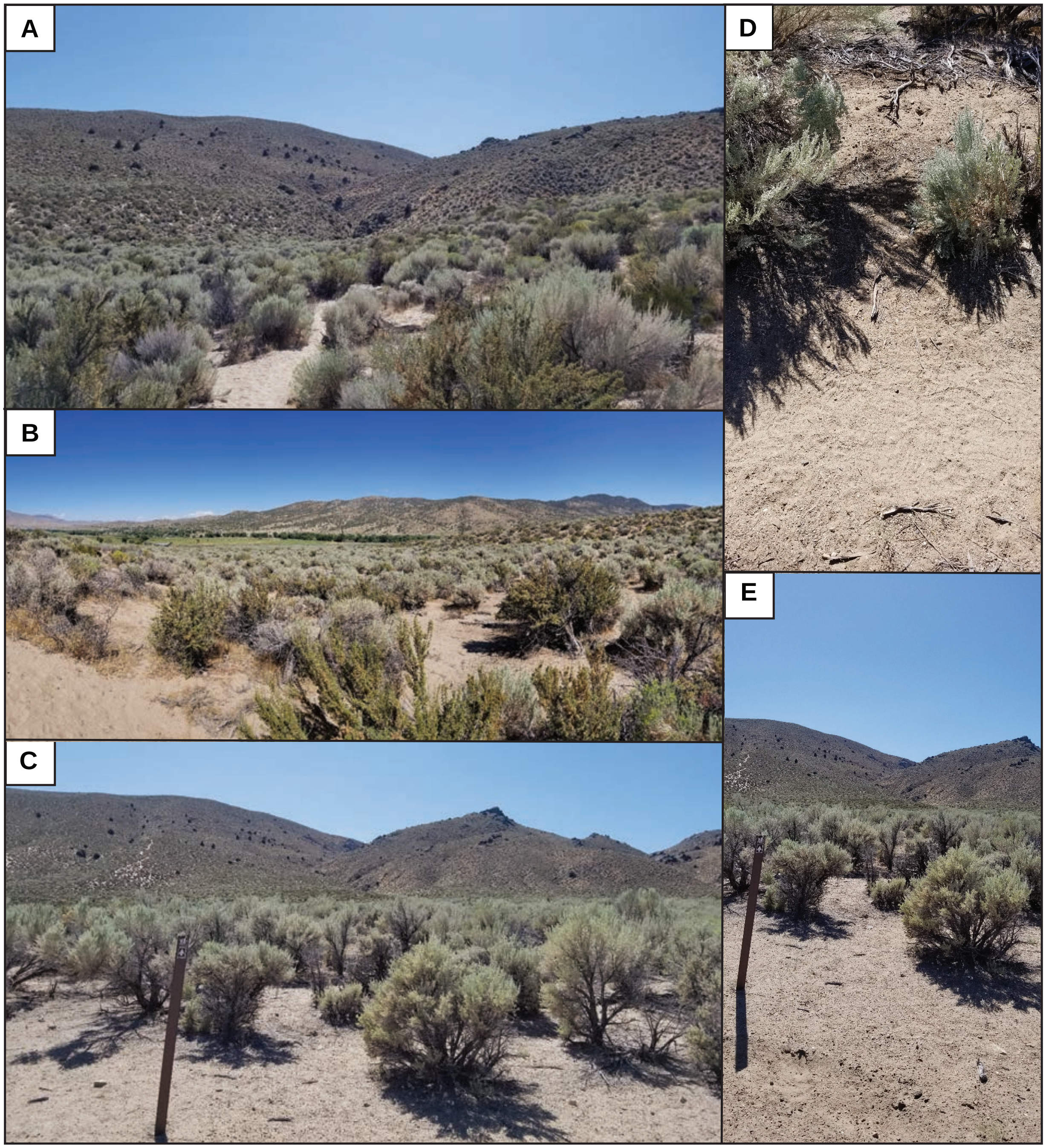


Figure 24. *Fan 115. View from upper fan showing sandy soil and desert shrub vegetation. (A) View from path looking southeast toward gulley that feeds fan and (B) looking down fan towards the Carson River floodplain. The lower fan is shown in panels C-D. (C –D) Surface of fan consists of sage brush often over 4 ft high growing out of sandy soil (mostly medium sized sand). Channel that feeds fan can be seen in center of panel A.*

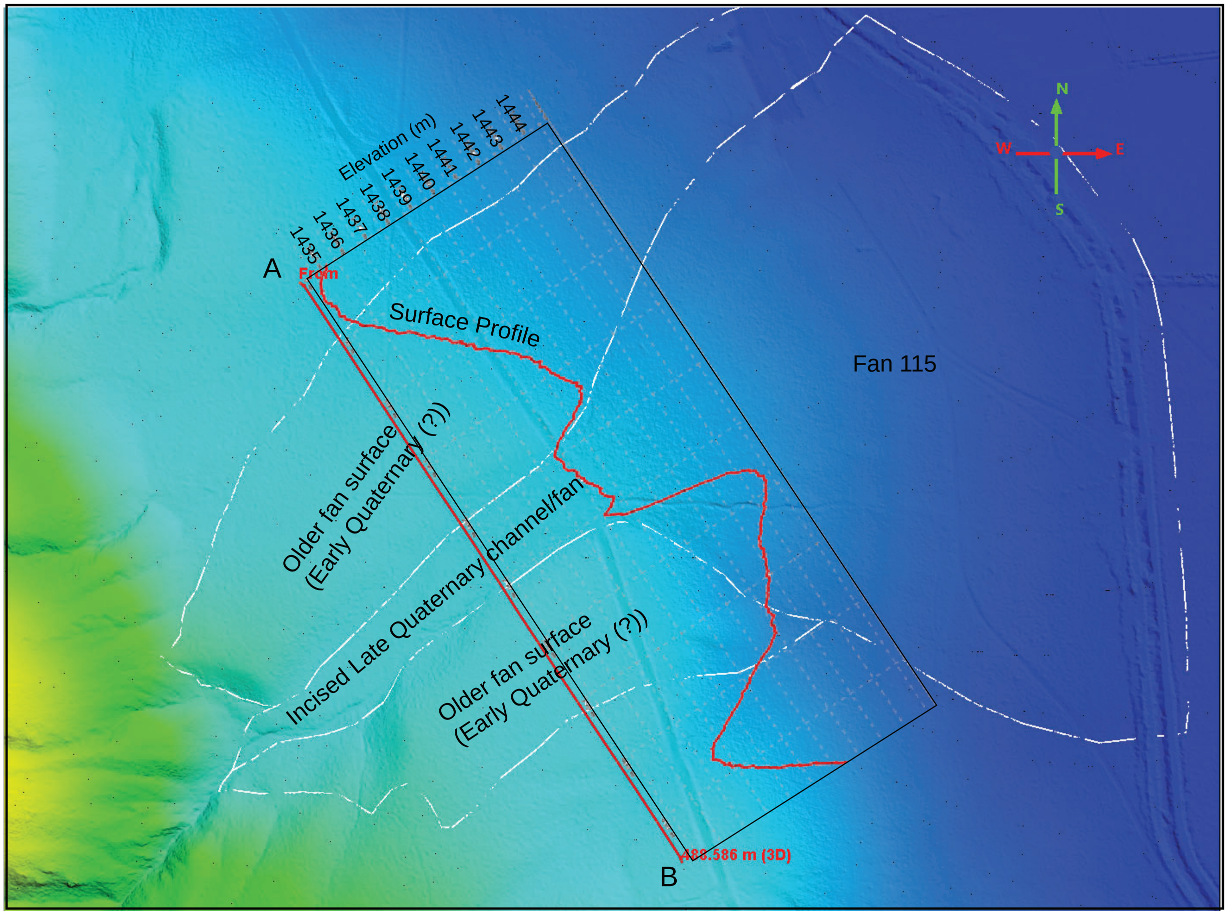


Figure 25. *Color shaded relief map of Fan 115. White lines show the mapped fan boundaries. There are two distinct phases of fan development expressed in this image. An older fan (assumed to be early Quaternary) formed under a different climatic regime with significantly higher sediment output with a more recent (Late Quaternary) feature incised into it forming a nested fan complex. Modern drainage in confined in the Late Quaternary channel that feeds Fan 115. The topographic profile shown in red highlights the difference in elevation between the two phases of fan development.*

complex (***Figure 25***). These older deposits were mapped by Bingler (1977) as *Quaternary older alluvium* (Qop) pediment deposits. The upper parts of the fan are constrained within an overfit channel (Note: fitness refers to the relationship of the channel relative to the stream within. An overfit channel is one where the banks are much wider than would be expected based on current conditions) that is incised into the older alluvium. Local relief is up to 0.3 to 0.6 ft (1 – 2 ft) and its surface gradient falls between 4° – 9°. Review of the historic aerial photography on GoogleEarth revealed possible evidence of recent activity seen on the April 2015 photograph that was not evident on the April 2014 photograph (***Figure 26***). The mid- to lower-fan soil at the surface is composed of sand with a minor component of pebbles and cobbles (angular to subangular). From the table top evaluation these would indicate that hyperconcentrated flows discharged over the upper reaches of the fan. The eastern toe of the fan is constrained by a canal, the construction of which appears to have cropped the toe of the fan.

The surface of the relict fan deposits north of the incised channel is characterized by relatively tall sage brush and sandy soil. A "ribbon" of modern alluvium exists in the center of the overfit channel (***Figure 27***). Recent alluvial deposits are composed of medium to coarse sand, granules and pebble gravel. Boulders and cobbles shown in ***Figure 28*** are angular and weathered. As described previously, the flow responsible for the modern alluvium does not have the competence to transport cobbles and boulders. The boulders and cobbles may be clustered or isolated. Where clustered they give the appearance of forming a lag deposit armoring channel bars. As such, the coarse material is believed to be eroded material, possibly lag deposits that originated from debris flow deposits transported downgradient under different climatic conditions.

In the area around the hydrologic apex, flows appear to spread out as sheetflows. This is recorded by patches or sheets of sand that spread out into the sage brush (***Figure 29***). The ribbons of sand seen further upgradient gradually disappear where the channel is no longer incised. As such, the sand patches likely represent deposition from sheetflows as storm flows spread out and lose competence.

Fan 116

Fan 116 is located along Carson River Road north of Fan 115 and emanates from Prison Hill in an area composed of Jurassic Dacite (***Figures 7 and 30***). The fan covers 139,539 m^2 (34.5 acres; ***Table 2***). The upper portion of the fan is generally undisturbed with a single incised channel running just north of center. This channel routes storm water through a small community east of Carson River Road. The single channel is tightly constrained for about 245 m (800 ft) before it reaches a culvert that takes flow under a road. The photographs in ***Figure 31*** show the incised channel with abundant angular boulders along the channel sides and floor. Modern deposits in the channel are sand and fine gravel (pebbles). The drainage is routed under Carson River Road via a corrugated metal culvert that then discharges into a well maintained channel lined with sand that routes flow through the housing community.

As with Fan 115, there appears to be a remnant of a much older fan surface along the southern margin that constrains the southern edge of the modern fan. An aspect noted in the field visit is that the surface appeared to have a greater abundance of angular boulders and cobles than Fan 115. The upper portion of the fan, as well as much of the southern distal portion of the fan, is covered with sage brush and there are no apparent secondary channels. On the east side of the road are several houses. The hydrologic apex occurs about 75 m (250 ft) east of the road and feeds an active alluvial zone. Overall, the fan is relatively steep with much of the surface falling in the 6° to 9° slope bin (***Figure 2b***). The eastern margin of the fan is constrained by a canal, the construction of which appears to have cropped the toe of the fan.

Although the analysis of the aerial photography and LiDAR imagery shows no indication of active alluvial deposition or debris flow activity, a flood event in 2014 reflects the potential

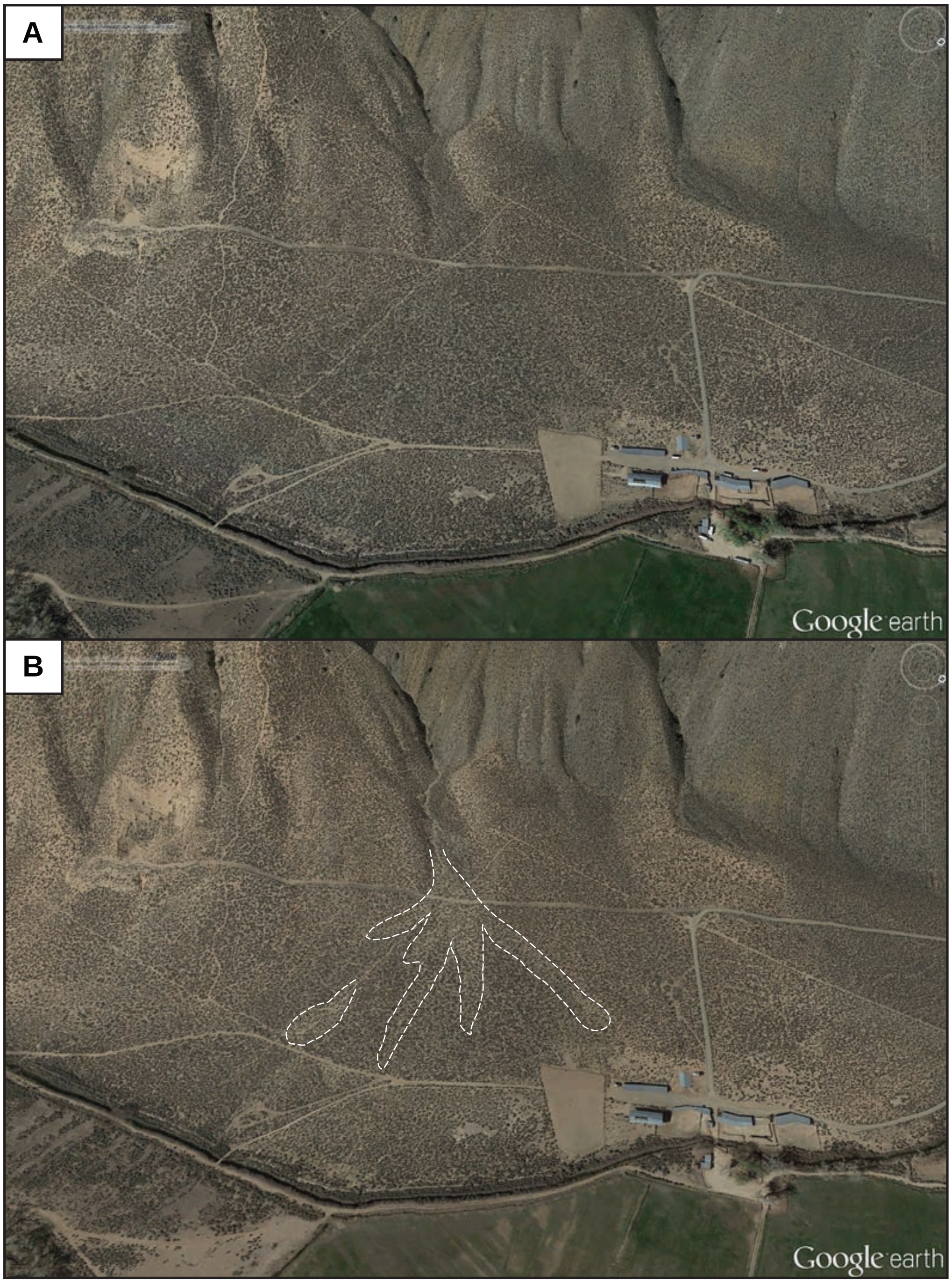


Figure 26. *Oblique view of aerial photographs showing Fan 115 taken A) April 2014 and B) April 2014. The lighter zones outlined on B do not appear on photograph A suggesting surface flow occurred between the time the two photographs were acquired.*

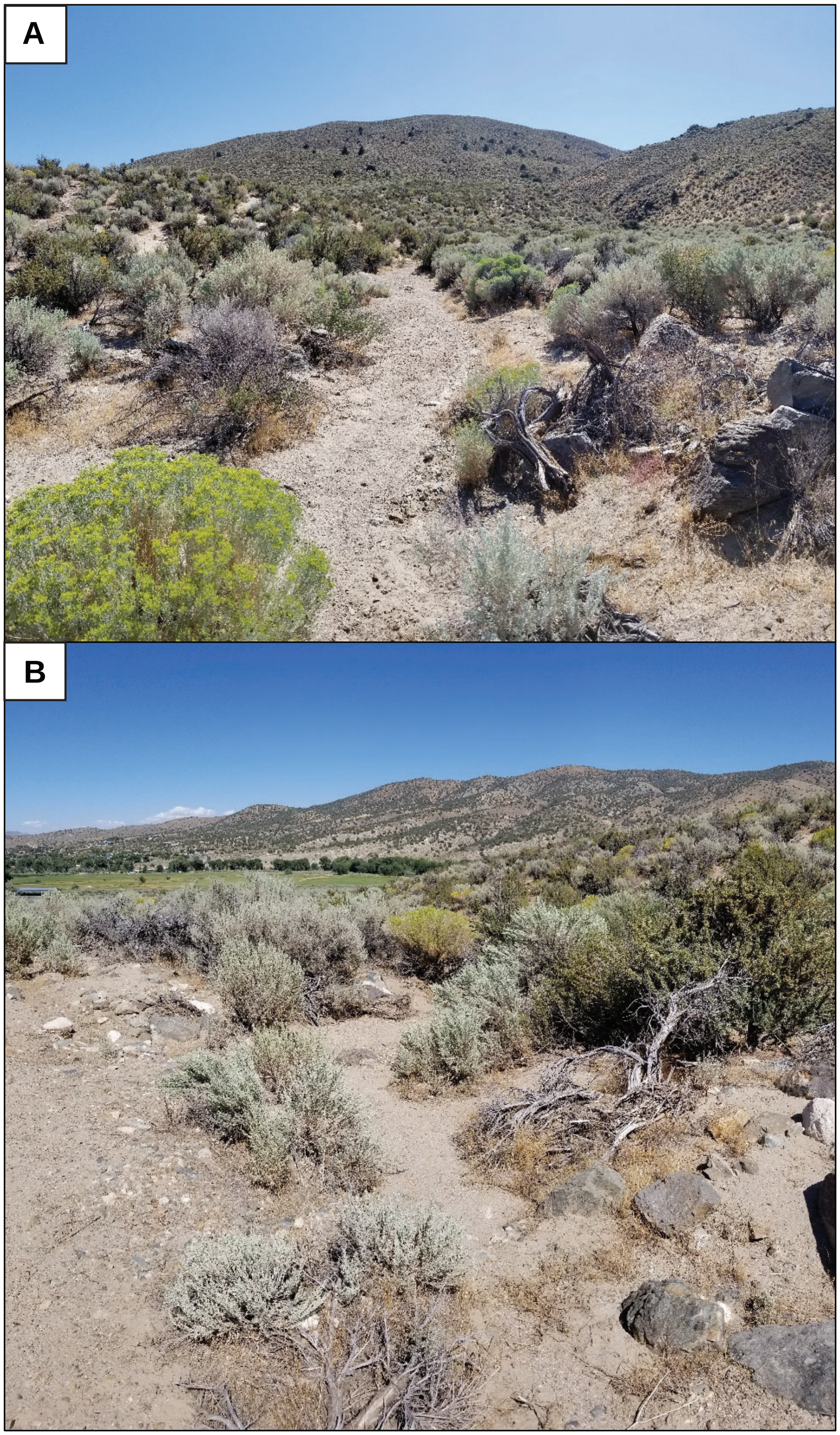


Figure 27. *Looking at active channel deposits upstream of hydrologic apex. This reach is confined by older alluvial deposits mapped as relict. (A) View from path looking southeast toward the gully that feeds fan and (B) looking down fan towards the Carson River floodplain.*

Figure 28. *Within active channel above hydrologic apex and bounded by older alluvial deposits. (A) Medium to coarse sand with granule to pebble sized gravel. Larger clasts are angular and appear to be an erosional log. B – C show large angular boulders along banks of active channel. Boulders and cobbles are angular to subangular and considerably larger than sandy alluvial deposits. Boulders/cobbles represent older debris flow deposits.*

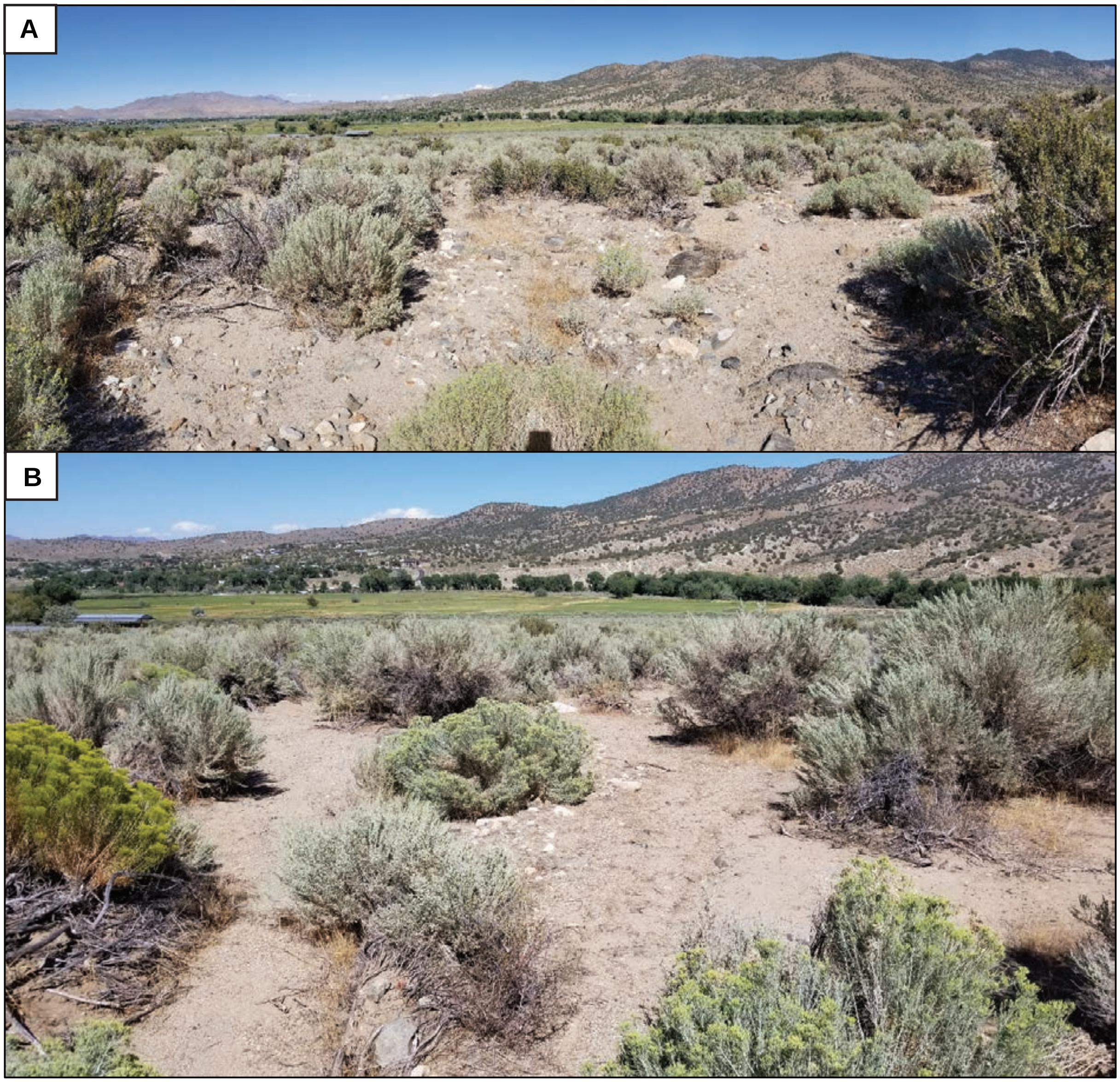


Figure 29. *Both photographs were taken at the approximate location of the hydrologic apex. Photograph B was taken slightly downstream from A. Note how the sand appears to spread out. This area is fed by "channelized" stream deposits upgradient. At this location, the flow appears to spread out representing distributary flow and sediment dispersal as flow exits confined reach.*

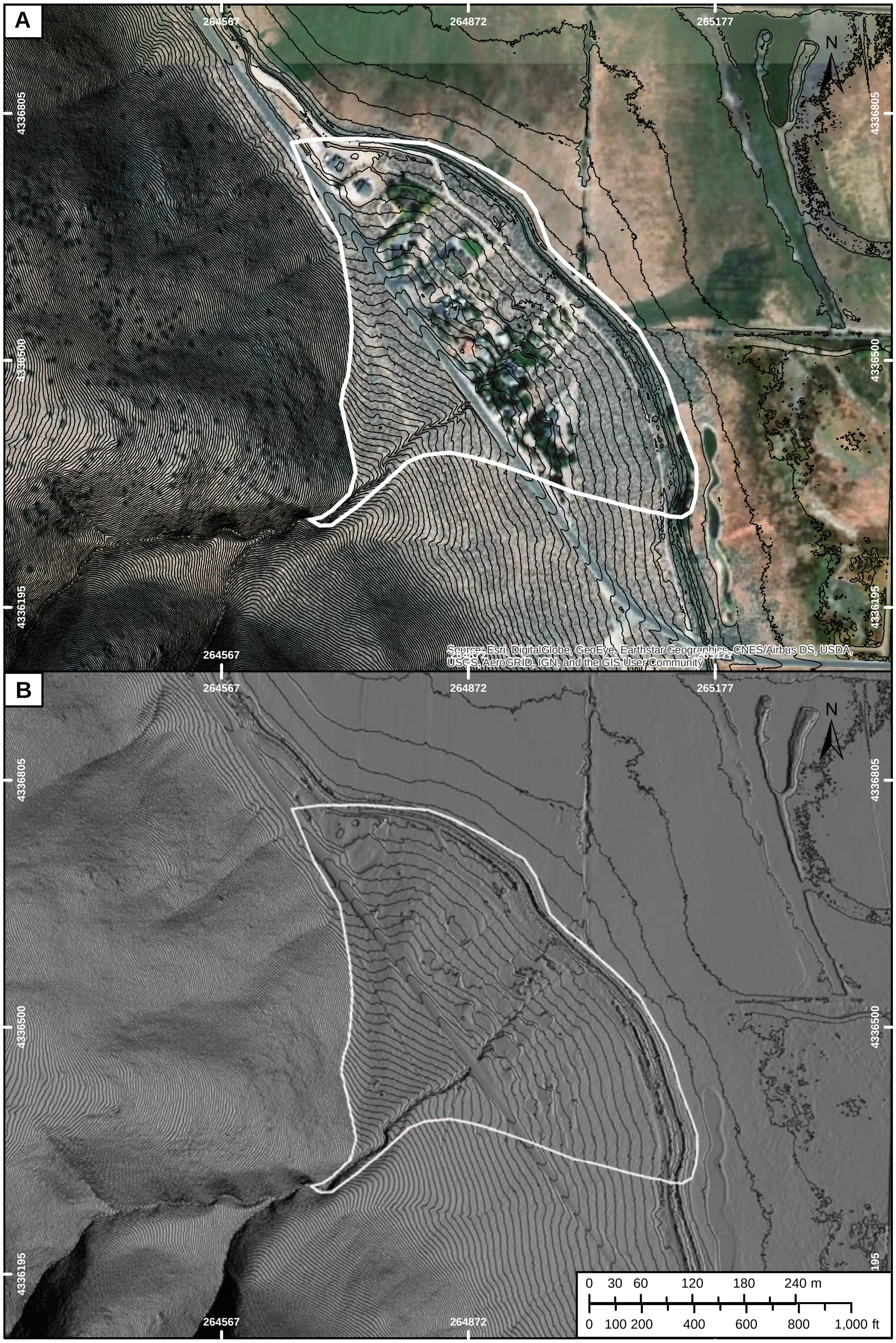


Figure 30. *Fan 116. A) With aerial photograph base from the ESRI World Imagery coverage sourced by Digital Globe. B) Hillshade elevation model generated in Quick Terrain Modeler. Both images show 1-m contours generated by Quick Terrain Modeler.*

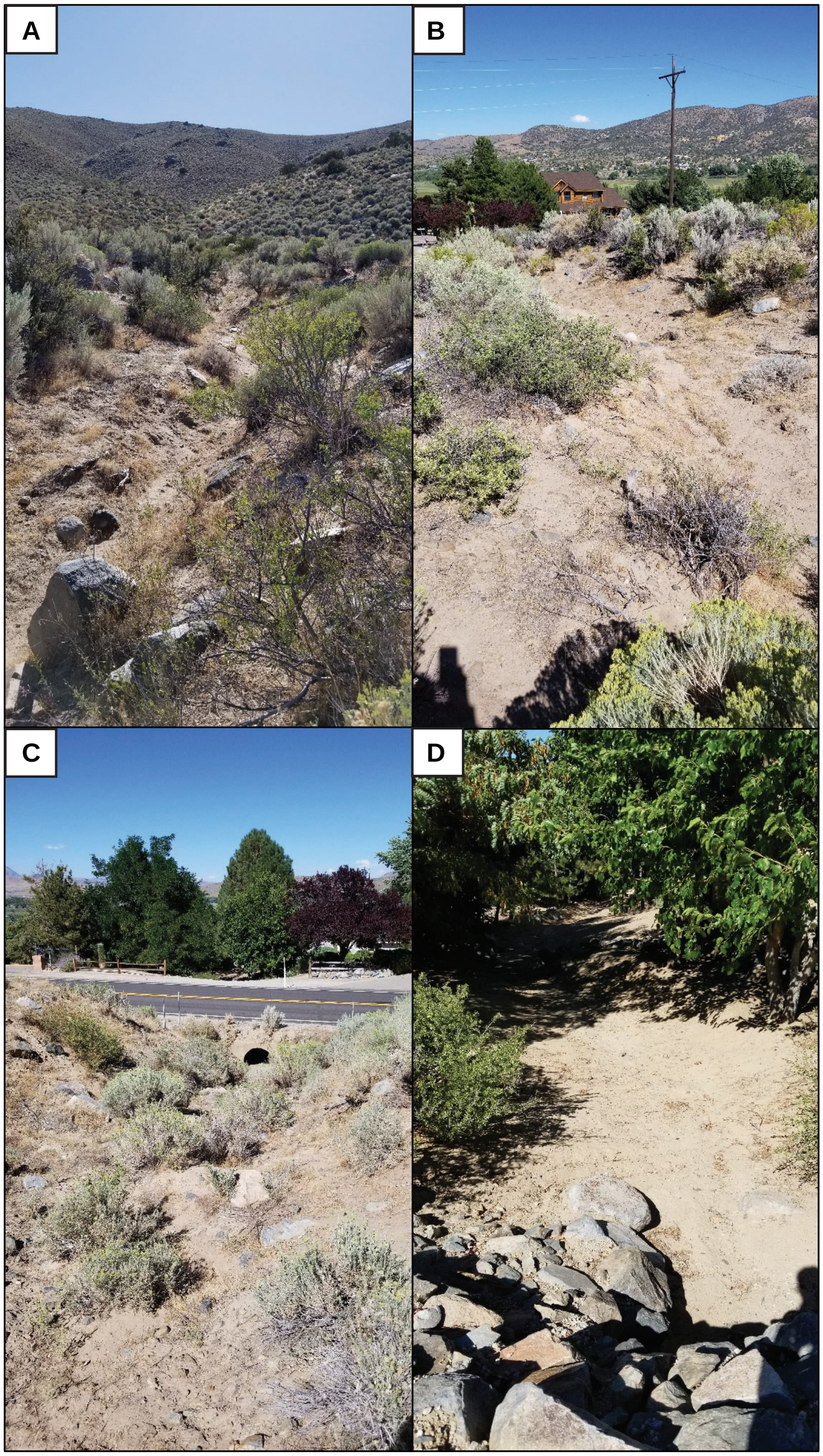


Figure 31. *Active channel on Fan 116. (A) Looking upgradient towards fan apex at incised channel. (B) Looking downgradient at incised channel. (C) Culvert under Carson River Road used to divert surface flow under road. (D) Well-maintained artificial channel used to divert storm water through housing area.*

hazard associated with these steep alluvial fans. ***Figure 32*** shows a series of photographs taken after a flooding event in 2014. According to R. Fellows (personal communication to J. Newton who was conducting the hydrologic modeling in parallel study) the culvert got blocked by debris during the flow and the then overtopped the road. Upwards of 2 ft of gravely sand covered the road and driveway to a nearby home. It is difficult to tell from the photographs if deposition occurred as a result of a hyperconcentrated flow or low-density sediment gravity flow (e.g., mudflow). Close examination of the photographs did observe some laminations in the sediment as well as channelization on the surface, but this could be a late stage dewatering effects. Regardless, the event shows that loose sediment in the fan's catchment is susceptible to mobilization during intense rainfall (and snowmelt) events. Based on the hydrologic modeling it appears that the culvert was undersized and would have been overwhelmed whether the culvert was blocked or not (J. Newton, personal communication). It is therefore unknown if the channel would have passed the event without significant damage.

Genova, NV

Figure 5 shows Fans 44 and 45 located north of Genoa, NV along the eastern toe of the Carson Range. A sharp demarcation occurs along the eastern toe of the Carson Range that marks the crossing of the Genoa Fault (***Figure 33***). West of the fault are Triassic age undifferentiated *metavalcanics, felsic shcist* and *Cretaceous granodiorite*, while to the east are alluvial fan complexes mapped as *Alluvial-fan deposits of the Carson Range* (Pease, 1980). The apices of Fans 44 and 45 coincide with the outlets of Adams and Childs Canyons. These steep, alpine canyons discharge sediment and water that feed portions of the *Alluvial-fan deposits of the Carson Range* mapped by Pease. Childs Canyon is the source area for Fan 44 while Adams Canyon discharges onto Fan 45.

Fans 44 and 45 have experienced significant growth over the past two decades (***Figures 34 and 35***). Historic aerial photography shows that as recently as 1992 there were only a few structures located on the mid- to distal-fan portions of the fans (***Figure 34***). Development can be seen starting around 2007 by which time Eagle Ridge Road has been installed, forming a loop connecting both fans and at least two building platforms had been build at that time. By November 2018, there is one house build on the mid-fan region of Fan 45 and seven new houses in the upper- to mid-fan regions of Fan 44. The development of the fans starting in 1992 and extending to present is shown on ***Figure 35*.**

<u>Fan 44</u>

Childs Canyon at the apex of Fan 44 is approximately 45 m (148 ft) wide and occupied by a braided stream (***Figure 36***). The canyon occupies a narrow, V-shaped valley incised into bedrock that extends nearly 2.4 km (1.5 mi) into the Carson Range. The catchment area feeding Fan 44 is 1,155,043 m^2 (285.4 acres) and the lobate fan covers 501,041 m^2 (123.8 acres: ***Table 2***). The incised braided channel extends nearly 280 m downgradient to where it converges to a single incised channel just upgradient of a drainage culvert that diverts water under the upper crossing of the loop road. The channel in this reach is bound to the south by a 1.5 m (5 ft) high levee as it exits Adams Canyon. The levee gradually tapers to

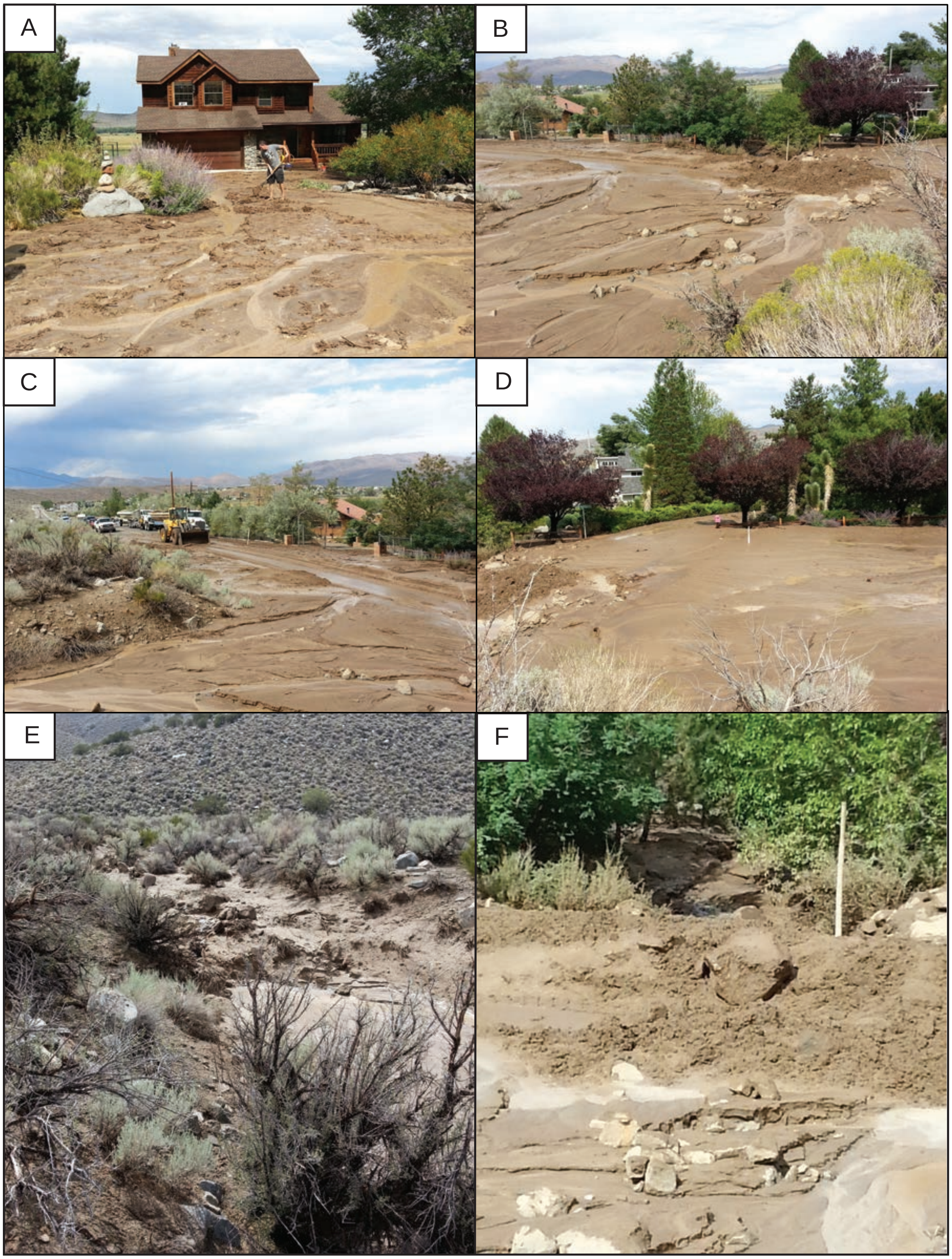


Figure 32. *Photographs of sand and gravel deposited on Carson River Road along Fan 116 during the 2014 flash flood. Photos provided by R. Fellows (Carson County). Photographs of the active channel E) looking upstream and F) downstream.*

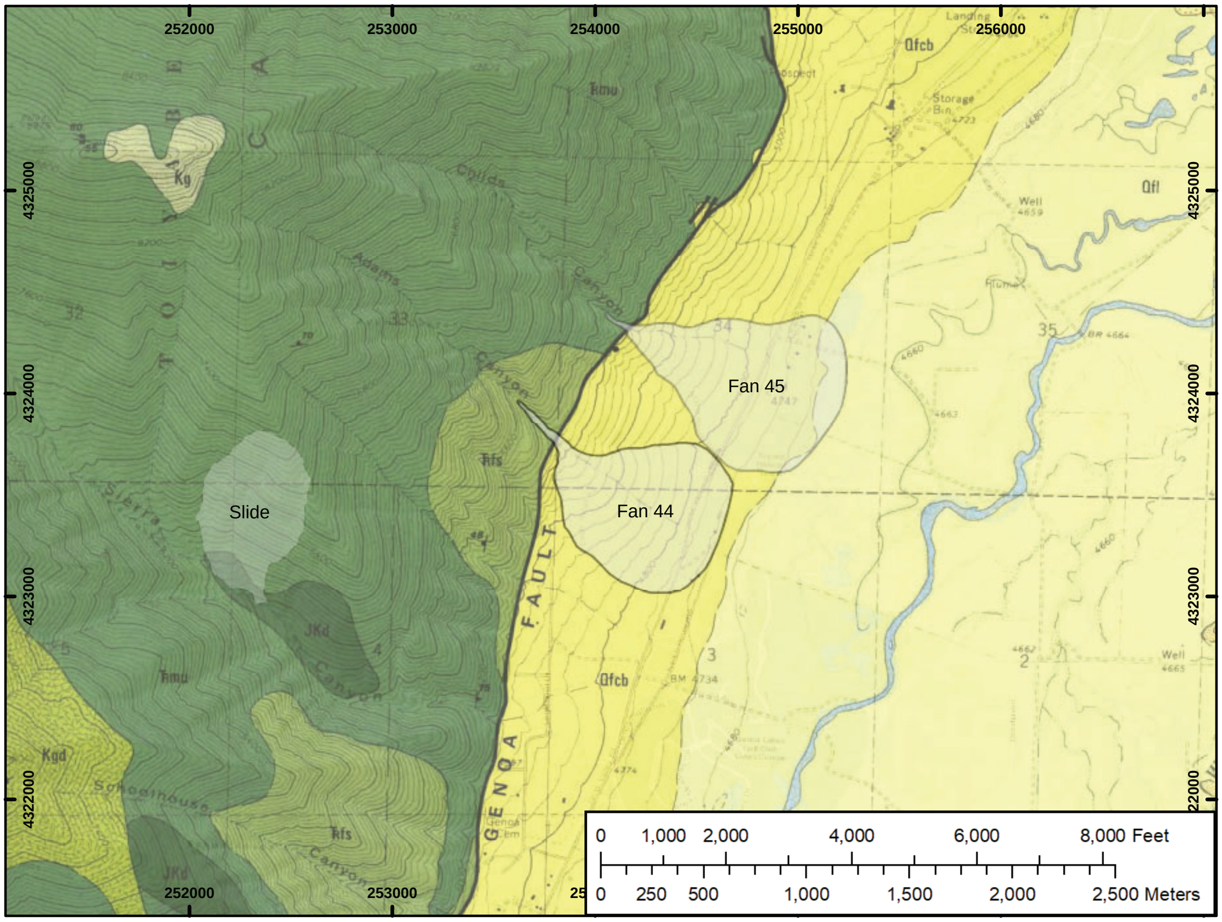


Figure 33. *Geology of the Genoa area from Pearse (1980). Shown are the locations of Fans 44 and 45, as well as an apparent slide in Sierra Canyon. Qfl = Quaternary flood-plain deposits of the Carson River, Qfcb = Quaternary flood-plain deposits of the Carson Range (non-indurated); QTg = Tertiary to Quaternary age Pediment deposits; Ts = Tertiary sediment; Kg = Crataceous granite; TRmu = Triassic metavolcanics; and TRfs = Felsic schist (undifferentiated).*

the east and pinches out just west of the loop road. The downstream side of the culvert approximates the hydrologic apex, below which channels appear to bifricate into a series of divergent braided channels. The topographic apex is located about 815 m (3,100 ft) west of Eagle Ridge Road and the slope from the apex to the road averages 10.4°.

Active drainage appears to be directed by the levee towards the culvert, below which flow diverges downgradient (***Figures 36 and 37***). Braided channels span approximately 60 m (197 ft) in width on the east side of the upper loop road and broadens to 240 m (787 ft) wide by the lower loop road, about 280 m (2,674 ft) down gradient. Outside of the active channel, and primarily to the south of the levee, the surface is characterized by a series of low relief (<0.5 m [1.6 ft]) ridges that form an anastomosing and divergent pattern. These represent former braided stream channels and bar deposits, presumably abandoned since building of the levee just downgradient of the topographic apex. It may also represent Holocene activity and abandonment as the current channel became incised.

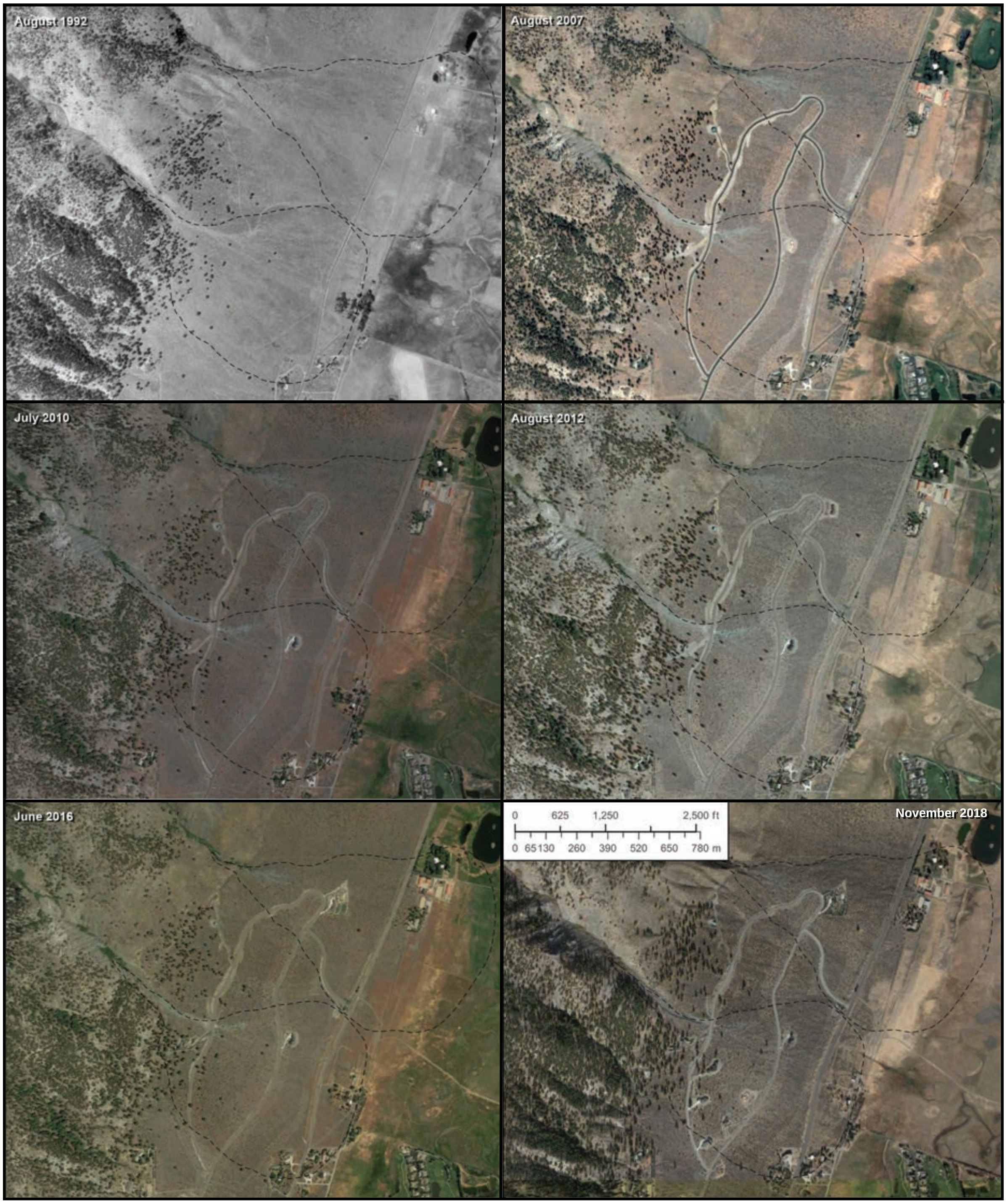


Figure 34. *Development of Fans 44 and 45. In 1992 there appear to have been 5 farms with numerous structures located along the toes of both fans. This remained until 2007 when a looped road had been installed and two construction sites can be seen on Fan 44 with a water tank located between the fans. In 2012 another construction site is located in the mid-fan region of Fan 44. This level of development remained until 2018 when five additional houses were built in the mid-fan region of Fan 44.*

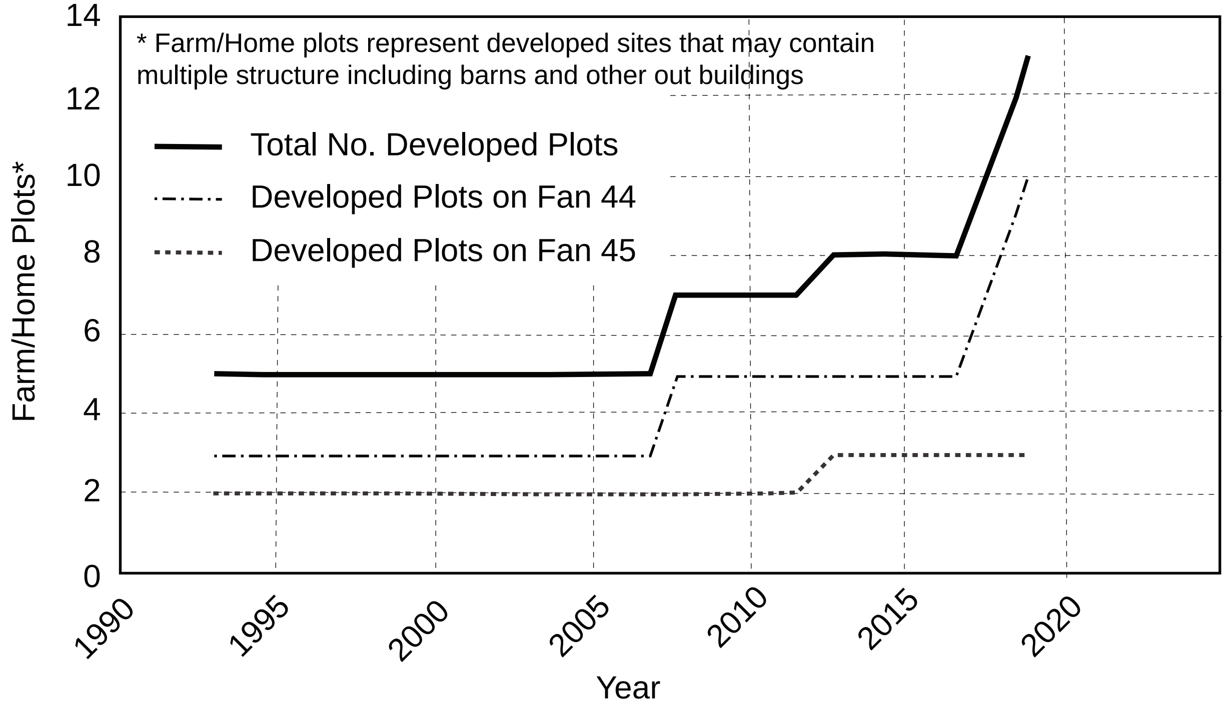


Figure 35. *Plot showing the development of Fans 44 and 45 since 1992. Five well-established farms were located along the toes of the fans until 2007 when the middle and upper regions of the fans experienced development. Rapid development of Fan 44 occurred in 2017-2018.*

Fan 45

Childs Canyon extends nearly 2.5 km (1.55 mi) into the Carson Range and is nearly 55 m (180 ft) wide where it crosses the Genoa Fault at the mouth of the canyon (***Figure 38***). The canyon is a little over 10 m (33 ft) wide where is discharges to the apex of Fan 45. The topographic and hydrologic apices coincide with the crossing of the Genoa Fault. Below the apex the channel becomes braided and diverges across the fan. The catchment area feeding Fan 45 is 1,151,927 m^2 (284.6 acres) and the lobate fan covers 568,586 m^2 (140.5 acres; ***Table 2***). The topographic apex is located about 650 m (2,132 ft) west of Eagle Ridge Road and the slope from the apex to the road averages 10.2°.

Approximately 200 m (660 ft) downgradient from the fan apex braided channels span the width of the fan, but to the southeast (downgradient) these diverge into two zones (***Figures 38 and 39***). The best preserved channels (presumably most recently active) occur in a zone 70 – 77 m (230 – 253 ft) wide along the southern (or southwestern) edge of the fan. In this zone, numerous anastomosing (and braided) channels run along the fan boundary, which the access road to the looped road roughly follows. This zone continues to the southeast to the outer boundary of the fan toe. There is also a berm built along a crossing road that extends from the southern third of the fan and across most of Fan 44. This berm represents an engineering effort to protect the road from flooding (thus fan activity).

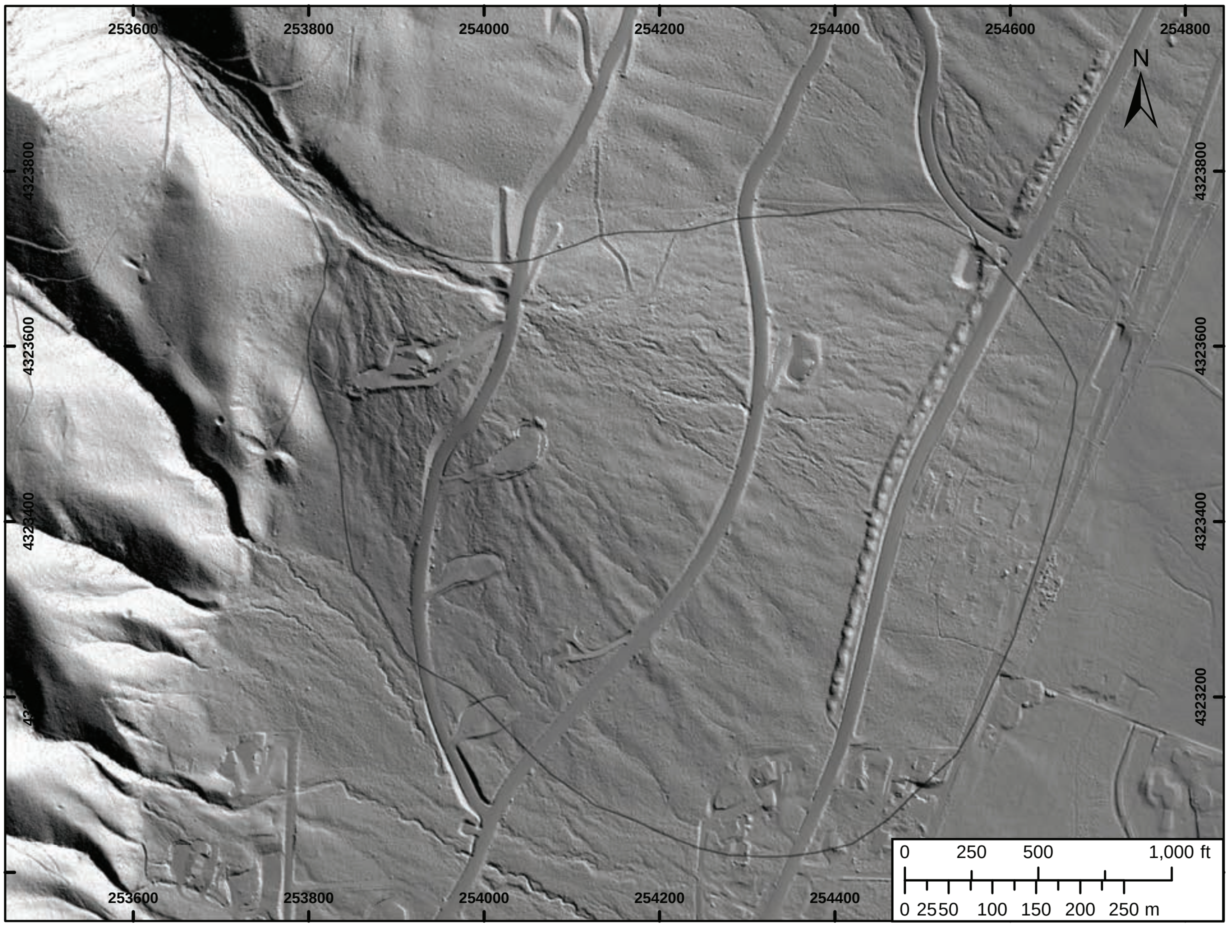


Figure 36. *Fan 44. Shaded relief hillshade image made using 2017 LiDAR data imported at a cell resolution of 0.29 m (0.95 ft) using the software Quick Terrain Modeler. Illumination is from the north to accentuate channels on the alluvial fan surface. Note fine, branching nature of channels on the northern half of the fan with gentler, smoothed surface in southern portion. Flat pads represent building foundations.*

The north to northeastern half of the fan is generally characterized by a series of elongate, rounded ridges, except for a narrow zone directly along the border that has relatively sharp banks indicating recent activity. The remainder of the area appears to be semi-relict (older but still active), abandoned braided channel deposits. The structure build at the bend in the loop road is located in this older surface with active channels both to the north and south.

Sierra Canyon

Although not included in the study area, there is a concerning feature on the north side of Sierra Canyon (adjacent canyon to the south of Childs Canyon). ***Figures 40 and 41*** shows a semi-circular feature that covers the entire south facing slope. This feature is the early phase of a large scale movement that if/when it fails will block off Sierra Canyon. The catchment above the toe has 997 m (3273 ft) of vertical relief and covers 663,387 m^2 (1639.2 acres). Even progressive creep on the slope will gradually impinge on the stream in

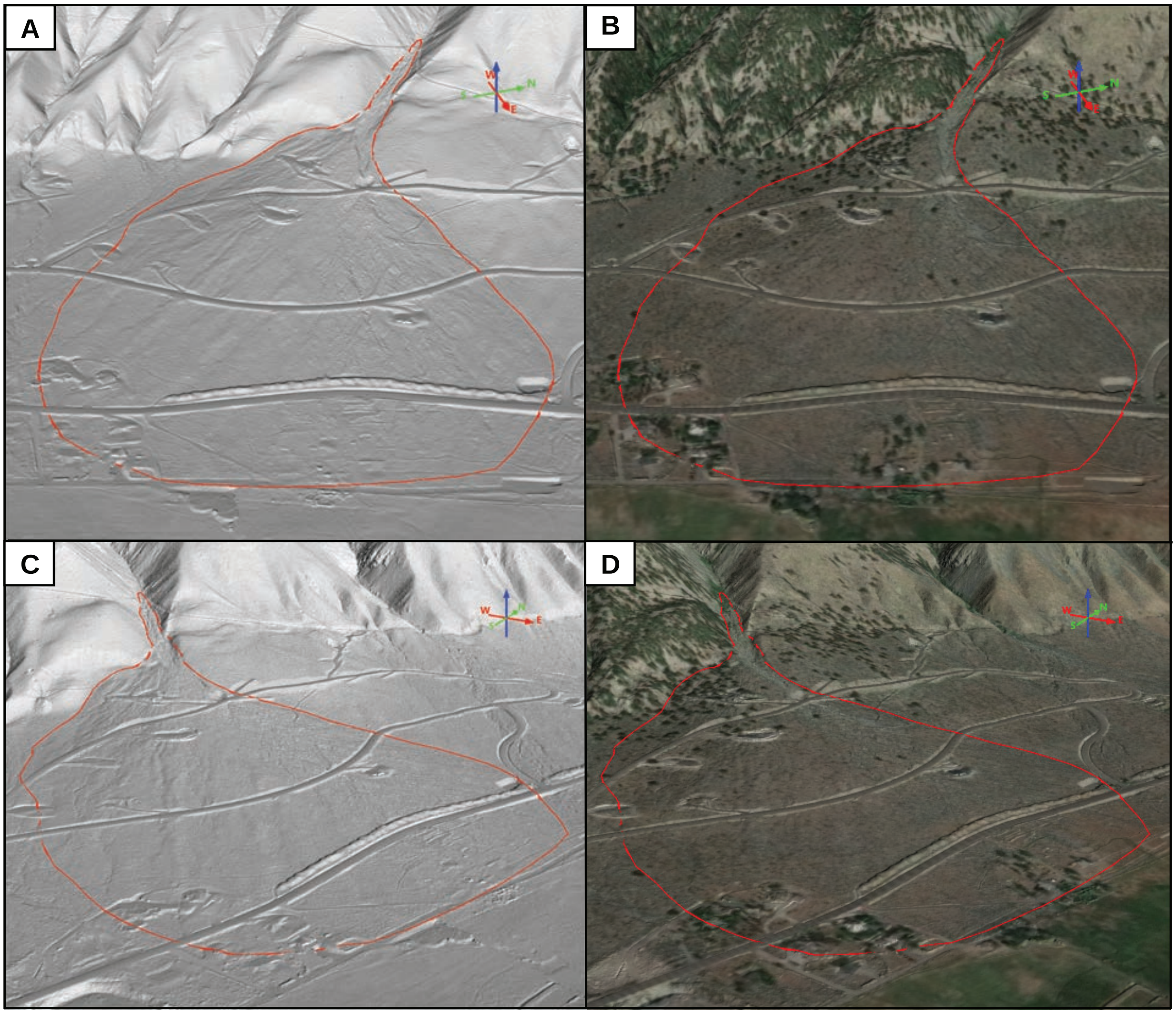


Figure 37. Oblique views of Fan 44. A) Looking towards the west-northwest and B) with aerial photograph superimposed. C) Looking towards the northwest and D) with aerial photograph superimposed. The "diamond-shaped" pattern in the shadows in the northern portions of the fan represent channel boundaries in the braided channels. The upper portion of this area corresponds with the grey zone when the aerial photograph is superimposed (Plate B) indicating areas of resent deposition. The surface is much smoother and more continuously covered by vegetation to the south as shown in Plates C & D.

Sierra Canyon and depending on the rate of movement could temporarily block the canyon. As flow is impinged upon creek, the sediment load to Fan 46 will increase as the stream undercuts the advancing toe. Catastrophic failure would lead to completely blocking the canyon with the potential for impounding water, subsequent overtopping, erosion and drainage. This could lead to very high sediment loads to Fan 46, with high risk for channel avulsion and associated debris flows. As such, Fan 46 should be classified as a high risk fan.

Figure 38. *Fan 45. Shaded relief hillshade image made using 2017 LiDAR data imported at a cell resolution of 0.29 m (0.95 ft) using the software Quick Terrain Modeler. Illumination is from the north to accentuate channels on the alluvial fan surface. Note fine, branching nature of channels on the northern half of the fan and along the southern fan boundary. Flat, semi-rectangular pads represent building foundations.*

Discussion/Conclusions:

Except for the wetland between Fans 79 and 81, all of the streams were dry indicating that they are ephemeral and only occupied during high precipitation rain and/or snow melt conditions. Modern sediment being deposited on these fans appears to be predominantly medium to course sand, with some gravel reworking. Sand is being deposited in sand ribbons where flow is confined and as sand sheets where flow is unconfined. Active “streams” are underfit with respect to the channels they occupy, indicating that the channels are relict features from a wetter climate. The competence of the flows transporting and depositing the sands is generally insufficient to have transported the boulders and cobbles common at the surface. These boulders and cobbles are typically angular, reflecting little to no rounding related to fluvial transport and mechanical

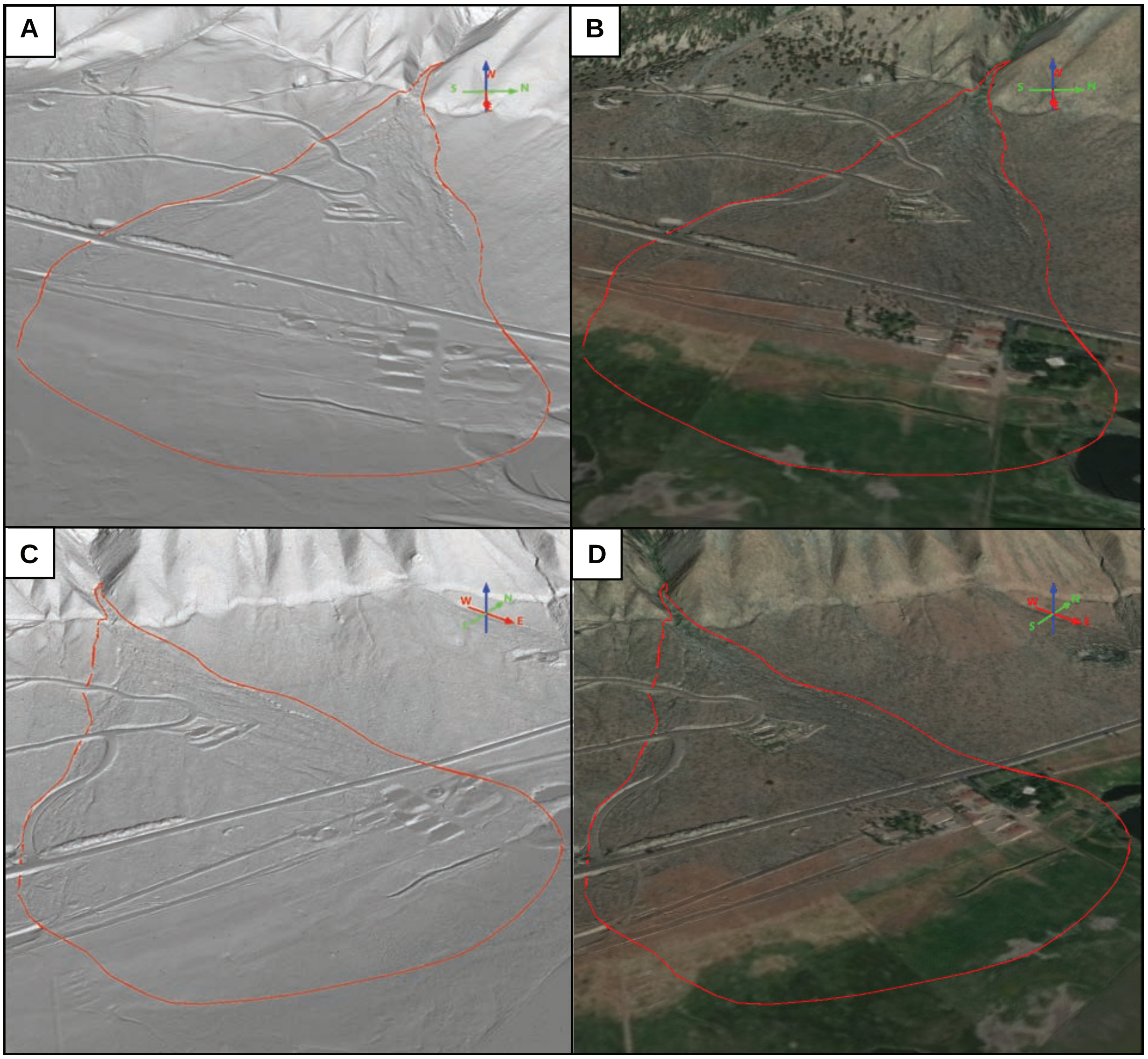


Figure 39. *Oblique views of Fan 45. A) Looking towards the west-northwest and B) with aerial photograph superimposed. C) Looking towards the northwest and D) with aerial photograph superimposed. Grey tones associated with recent deposition can be seen near the fan apex on both B and D. Active channels appear present in the mid-fan region along the northern border and along the length of the southern border (A & C).*

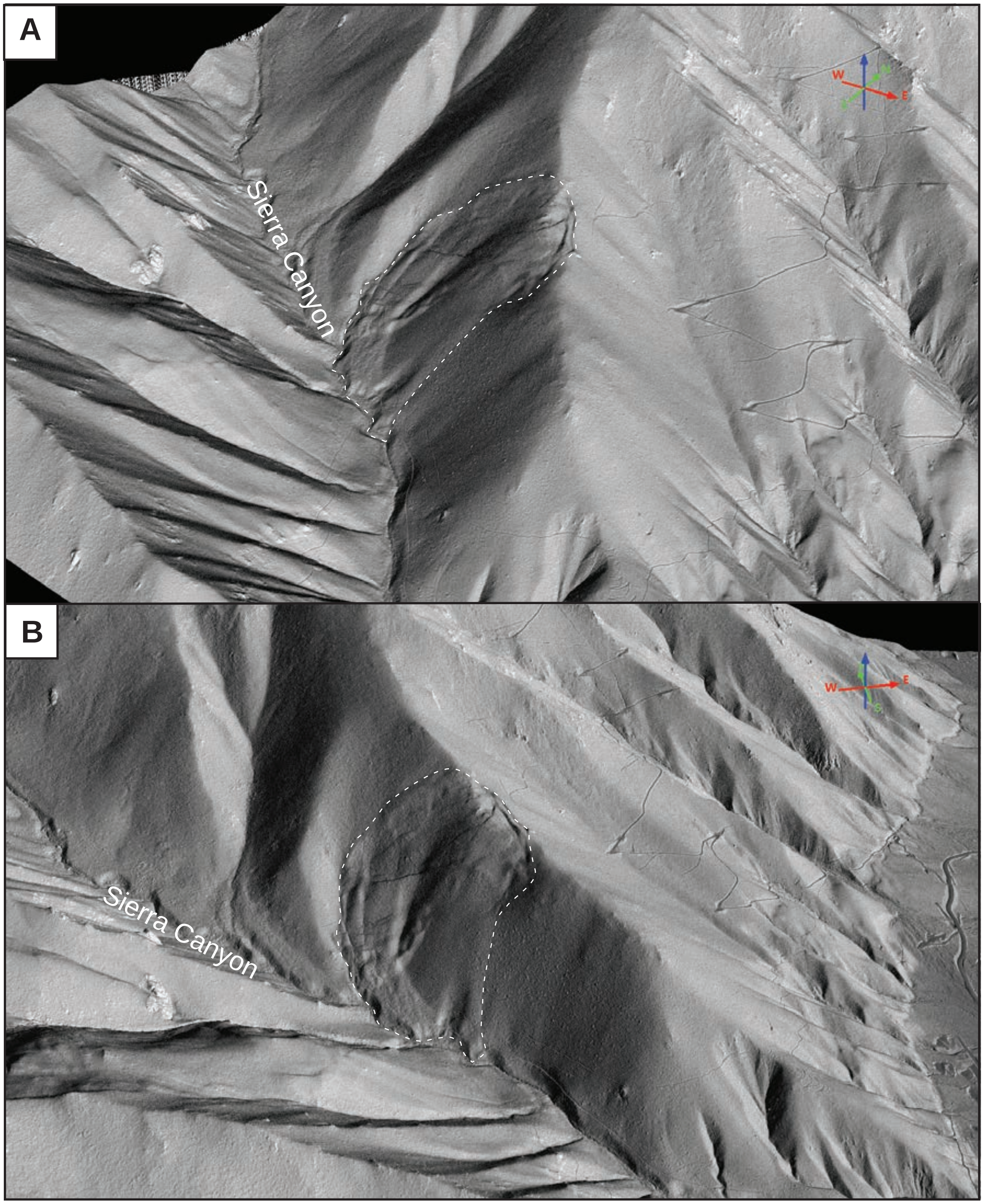


Figure 40. *Oblique images of the LiDAR data showing Sierra Canyon. Note the deformed area on the south facing slope of the canyon marking the location of scarps and ridges associated with downslope earth movement (e.g., landslide). The landslide appears to be in early formation, slow soil creep and rotational sliding. The toe is being undercut by stream activity in Sierra Canyon as the tow advances down valley. Looking to the A) northwest and B) north-northeast. Dashed line marks outline of landslide.*

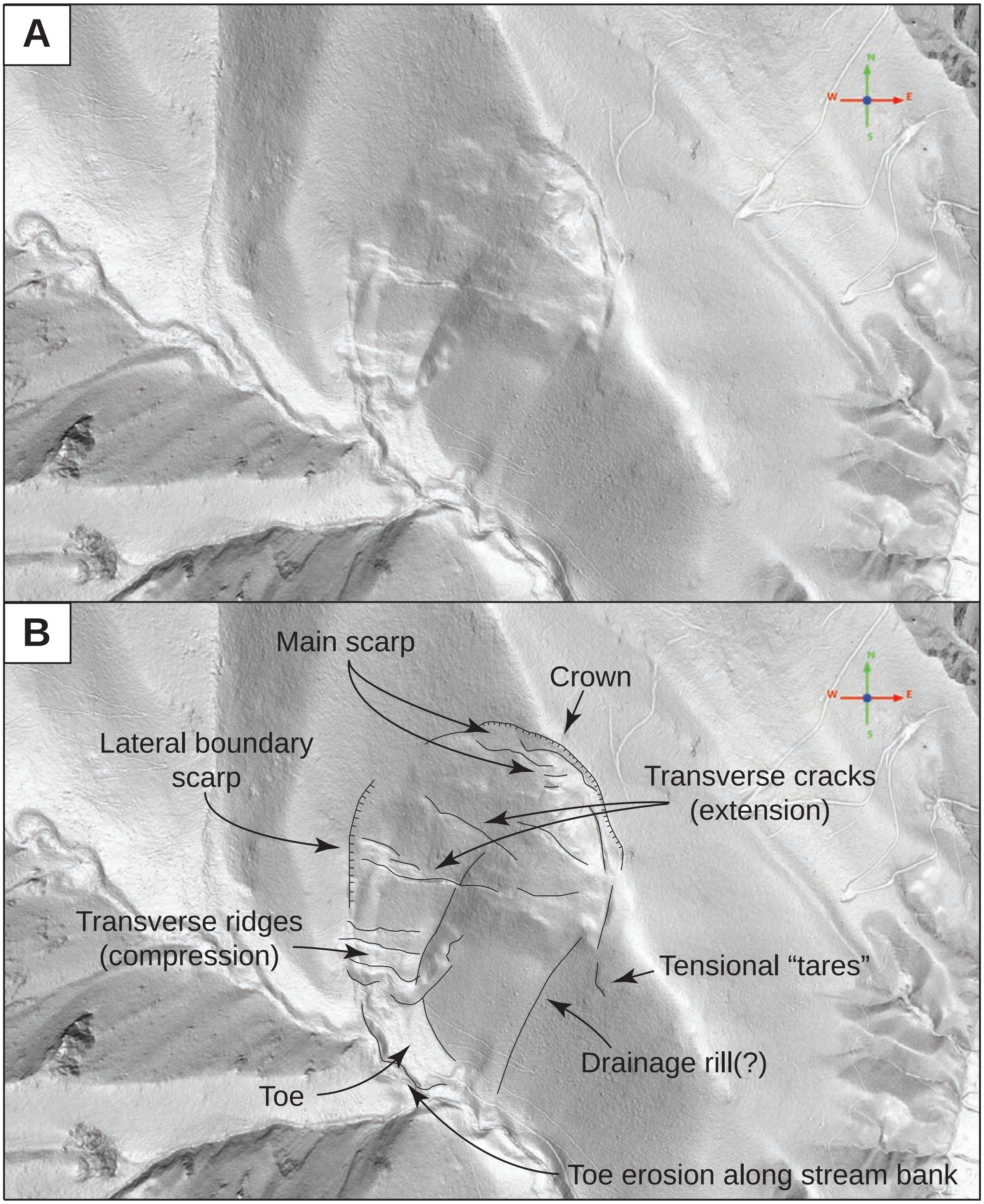


Figure 41. *Oblique image of the south facing slope near lower end of Sierra Canyon, Douglas County, NV. Unannotated image and B) annotated. Sierra Canyon feeds Fan 46. Terminology adapted from USGS Fact Sheet 2004-3072.*

weathering. The clasts also often have a tarnished and weathered appearance indicating they have been exposed to long periods of chemical weathering. In many cases, they look like erosional remnants not associated with modern deposition. Boulders and cobbles are also common to at least the mid-fan regions. These clasts were likely transported onto the fan by debris flows during wetter climatic conditions, most likely during the Quaternary when fan aggradation was predominant. There are no stratigraphic exposures in these fans to evaluate historic modes of deposition. Despite these observations, debris flows may potentially be generated in the current climate but their occurrence is likely rare. When they occur, it is likely that debris flows would be restricted to the feeder channels and upper reaches of the fan. An exception would be large slope failures like the one highlighted in Sierra Canyon where a significant portion of the slope is experiencing progressive failure. This feature should be monitored to determine the rate of failure and to evaluate downgradient risk.

Table 2 provides a summary of the observations made on the eight fans investigated during this study. All of the fans are relatively small, ranging in size from 13 to 141 acres. The fans are also relatively steep, often exceeding 6° while Fans 44 and 45 exceed 10°. They are not highly dissected, generally having relatively smooth, low relief surfaces. The fans with lower slopes are least likely to experience sediment transfer by destructive debris flow processes. Fans 44 and 45 with surface slopes in excess of 10° are the most likely to experience destructive debris flows. All of fans should be classified as composite fans in terms of fan building processes, as their formation was controlled by both fluvial and debris flow processes.

Fans 79 and 82 exhibit the gentlest slopes, only exceeding 6° near the apex. These fans differ in morphology, as Fan 82 has a very long feeder channel that is incised into alluvial terrace deposits and Fan 79 is a long fan that extends well out into the Carson River Valley away from the mountain range. Sediment transport to the distal regions of these fan would generally require alluvial transport while sediment gravity flow deposits (e.g., debris flows) would most likely result from local slope collapse. The overall low gradients on Fans 79 and 82 are indicative that deposits from hyperconcentrated flows constitute a greater percentage of the fans architecture relative to the other fans. In the Indian Hills area, Fan 81 exhibits steeper slopes associated with close proximity to the mountain front. The fans in the Prison Hill area exhibit surface slopes in excess of 6°. A qualitative assessment based on slope would be that debris flow contribution has been more prominent for Fans 116 and 81than Fans 78 and 115. Slope gradient and surface roughness are much greater for Fans 44 and 45. These fans should be considered the least stable of the eight investigated. Slope gradient in excess of 10° is indicative of a large debris flow contribution while the surface roughness reflects a history of erosive events.

Due to the highly variable and unpredictable behavior of alluvial fans and the controlling factors dictating storm water discharge, sediment entrainment and deposition, it is difficult to predict what the future dynamics of these fans will be. However, six of these fans (44, 45, 78, 81, 115 & 116) show some indication of activity in the past 30 years (e.g., photographic record available on GoogleEarth). Fans 79 and 82 show no evidence of activity from the aerial photographic analysis, but this is not stating that some surface flow with localized erosion and deposition does not occur.

There was no observation that debris flows occurred on any of these fans in recent history, but with surface vegetation consisting primarily of shrub vegetation disturbance may be less visible than if forested or grass covered. This is not to say that debris flows will not occur on these fans, just that such events have not occurred regularly in the recent past. Current conditions appear to favor such events being limited to the steep mountain valleys or upper fan regions where close to the mountain front; however, Fans 44 and 45 are the most likely to experience destructive debris flow events that may extend well onto the fan surface.

Genoa, Nevada

Fans 44 and 45 are considered the highest risk fans of those looked at in this study. Active fan surfaces cover a significant portion of these fans. The active fan surfaces correspond to the zones with well-defined braided stream channels. The sharp appearance in the LiDAR imagery reflect recent activity. The zones with more rolling ridges and channels may still be re-activated but are not the primary active channels and thus have been mapped as Susceptible. There are zones up near the apex that appear inactive and/or relict.

Active Fan Summary

Fan activity is depicted in ***Figures 42 – 44.*** Areas that show evidence of recent activity are mapped as "Active". These are areas that show evidence of recent sediment deposition, contain the most "youthful" looking channels, or correspond to predictive flooding from the hydrologic modeling (USACE 2020). Areas mapped as "Susceptible" are located downgradient of "Active" areas. These are areas likely to be reactivated as flow progresses downgradient, but because of the dynamic nature of these channels, flow paths cannot be predicted. "Inactive" areas are those that do not appear to have been active for a long time or are protected behind other structures, such as the levee near the apex of Fan 44, or may be at a higher elevation than the active floodplain. "Relict" surfaces are from landforms that are not active and appear to represent Quaternary features, such as old fan terraces. "Active Channels" are those features that currently route storm water and "Undifferentiated" have not been classified. Areas mapped as "Modified" either have structures build on them or are covered by pavement (roads/parking lots).

Descriptions of the active fans (44, 45, 78, 81, 115, and 116) is provided below:

<u>Fan 44</u>

Fan 44 exhibits a classic fan shaped outline that is minimally constrained along its northern and southern boundaries (***Figure 37***). There appears to be a man-made levee on the south side of the feeder channel that extends from the topographic apex to the hydrologic apex where flow is conveyed under Eagle Ridge Road via a culvert (***Figure 42***). The levee appears to have been built to protect a house just to the south of the topographic apex. The

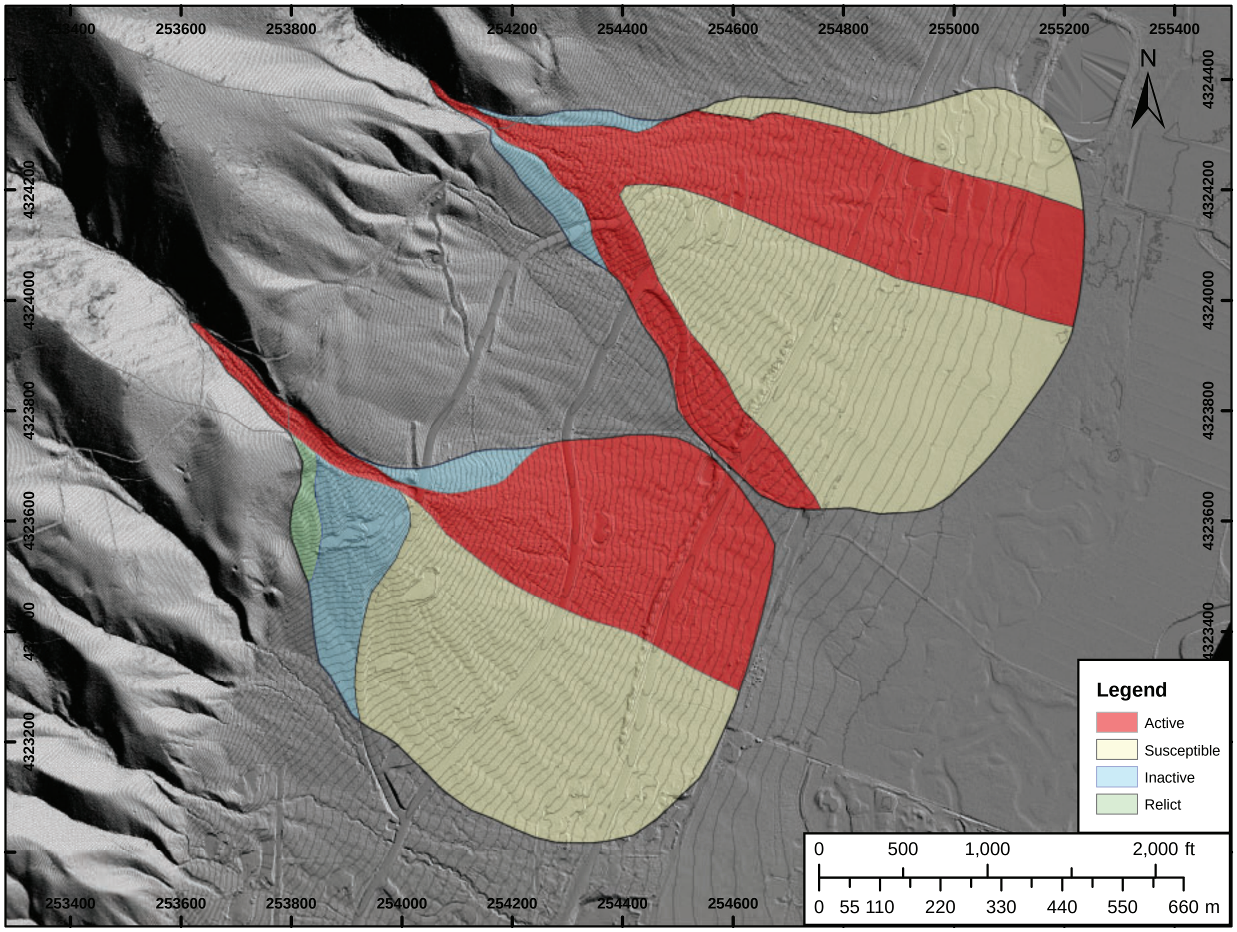


Figure 42. *Fans 44 and 45 apparent activity/hazards based on LiDAR and aerial photography evaluation. Active areas shown evidence of recent channel activity and sedimentation. Susceptible area are those downgradient of active zones or other areas likely to experience flooding during channel avulsion. Inactive area are those typically located above active flood zones or sheltered behind levees and do not appear to have experienced recent alluvial deposition. Relict zone appear to be older surfaces, probably of Late Quaternary age.*

northern half of the fan surface is incised by numerous bifurcating channels that appear sharp in the LiDAR imagery. These are distinctly different that the broader, smoother channels on the southern half of the fan. As such, it appears as though the northern half of the fan is currently active in distributing rain and snow melt surface water off of the fan. If a debris flow were to originate in the valley above the fan it is likely to overwhelm the upper culverts below Eagle Ridge Road causing channel migration and avulsion.

<u>Fan 45</u>

As with Fan 44, Fan 45 exhibits a classic fan shaped outline that is minimally constrained along its northern and southern boundaries (***Figure 38***). The LiDAR imagery shows that surface flow diverges (Active) slightly below the topographic apex redistributing water

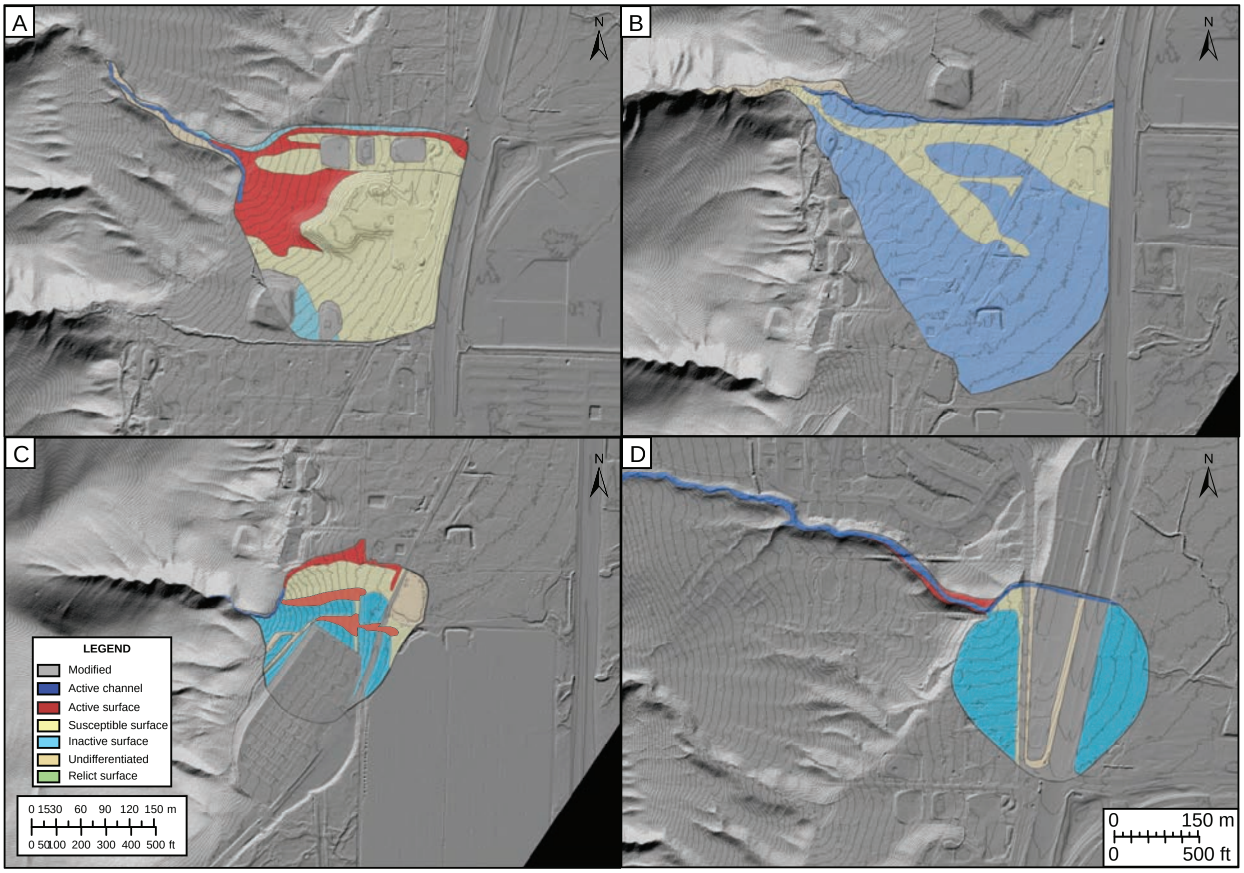


Figure 43. Fan hazard mapping. A) Fans 78, B) 79, C) 81 and D) 82. Apparent activity/hazards based on LiDAR and aerial photography evaluation. Active areas shown evidence of recent channel activity and sedimentation. Susceptible area are those downgradient of active zones or other areas likely to experience flooding during channel avulsion. Inactive area are those typically located above active flood zones or sheltered behind levees and do not appear to have experienced recent alluvial deposition. Relict zone appear to be older surfaces, probably of Late Quaternary age.

to the north and south (***Figure 42***). In these areas there are strips of well-defined, sharp braided channel systems. The central portion of the fan is characterized by broad, more gently rolling ridges and channels. These represent older channels currently not as active as the braided channels closer to the fan boundaries but could become active in the future through channel migration and/or avulsion (Susceptible)

Indian Hills

In the Indian Hills area, Fans 78 and 81 appear the most active. These fans are closer to the mountain front and exhibit slightly steeper slopes. Their surface classifications relative to apparent activity are shown in ***Figure 43a***. Sand deposits attributed to sheet wash are common near the apex of Fan 78 as well as ribbons of sand deposits along the floor of the overfit channel. Areas downstream of these deposits are considered susceptible during a large event.

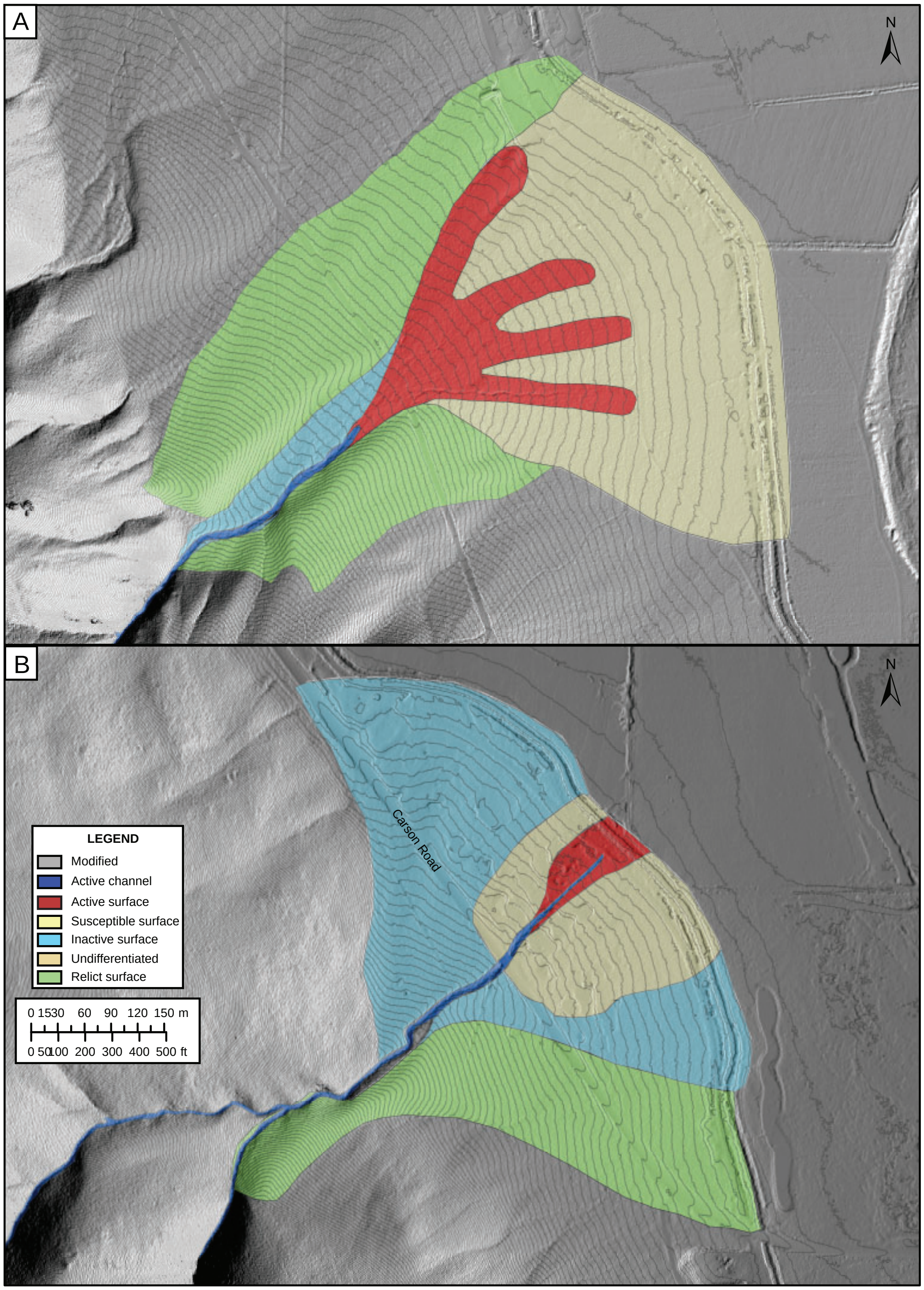


Figure 44. *Fan hazard mapping. A) Fans 115 and B) 116. Apparent activity/hazards based on LiDAR and aerial photography evaluation. Active areas shown evidence of recent channel activity and sedimentation. Susceptible area are those downgradient of active zones or other areas likely to experience flooding during channel avulsion. Inactive area are those typically located above active flood zones or sheltered behind levees and do not appear to have experienced recent alluvial deposition. Relict zone appear to be older surfaces, probably of Late Quaternary age.*

Fan 78

Fan 78 is highly disturbed with several large excavation as well as several building pads for houses (***Figure 43b***). Primary storm drainage follows the active channel along the northern boundary of the fan along a drainage ditch: however, southeast of the topographic apex is a shallow, broad depression. Aerial photographs from 2015 and 2017 (***Figure 12***) show lobate lenses of light coloration that likely represents recent deposition from sheetflow events. Evidence of sheetflow deposits were observed in these areas during the site visit. These areas are mapped as Active in ***Figure 43b***. Gullies (likely enhanced by excavation) along the upgradient side of the large excavation are indicative of surface flow capture. As the upper portions of the fan are generally "Active," avulsion and downgradient flow means much of the fans surface is "Susceptible" to flooding.

Fan 81

Figure 19 shows at least two areas that have experienced recent flow and erosion of the fan surface, as well as general zone of alluviation along the northern boundary where storm water likely ponds in near flat laying areas before draining to the east. A zone of potential concern is along the "Active Channel" where overbank flow has caused minor channel development (***Figure 43c***). During high flow conditions, this could be an incipient area for channel avulsion. The other "Active" zone on the fan is a product of surface drainage being re-directed around the self-storage facility. Downstream of the drainage diversion there is evidence of channelization caused by focused surface runoff. To prevent ponding of water, a levee (or berm) has been intentionally breached to allow eastward drainage.

Prison Hill

There is a marked contrast in the apparent activity on the surfaces of the two fans investigates along the east side of Prison Hill (***Figure 44***). Recent sand deposits in the vicinity of the hydrologic apex as well as discoloration in the aerial photographic analysis (***Figure 26***) are indicative of recent distributary flow of Fan 115. Any area downgradient of these areas is considered susceptible to flooding and sedimentation. Activity on Fan 116 appears to be more focused on the main channel that crosses the center of the fan. Flow appears to diverge after crossing below Carson Road; however, deposition associated with the 2014 flood indicates that extreme events can occur (***Figures 6 & 32***).

Fan 115

Activity on Fan 115 follows the same line of evidence as Fan 81. An aerial photograph from 2015 shows light surface discolorations not seen on earlier photographs. This zone of discoloration diverges below the hydrologic apex indicative of possible sheetflow dispersing downgradient. This area is mapped as "Active" and forms a series of fingers that correspond to apparent zones of recent deposition (***Figure 44a***). "Channelized sand ribbons" appear to shift towards sand sheets in this area, indicating that constrained flow shift to unconstrained flow in this area. All areas downgradient of the "Active" areas are considered to be "Susceptible" to flooding. The green unit shown on ***Figure 44a*** represent "Relict" fan surfaces that the current fan has incised into.

Fan 116

The active classification on Fan 116 is associated with the area east of the hydrographic apex, which forms a thin alluvial zone that extends out to the toe of the fan (***Figure 44b***). The channel feeding the hydrologic apex is deeply incised and stable. The channel above the culvert is stable and that downstream of the culvert is well-maintained by the community. Although this lower area is active, flooding looks to be generally well confined. However, the 2014 flooding demonstrates the potentially destructive hazards associated with the fan.

References

Bingler, Edward C., and Susan L. Nichols. Geologic map of the New Empire quadrangle. Reno, Nevada, Nevada Bureau of Mines and Geology, University of Nevada, 1977.

Floyd, B., Leonard, C., and Hunter, L.E., 2017. Alluvial fan mapping for the Carson River Watershed. Methodology. Sacramento, California. U.S. Army Corps of Engineers. Report prepared for the Carson Water Subconservancy District.

Jackson, L.E., Jr., Kostaschuck, R.A., and MacDonald, G.M., 1987. Identification of debris flow hazard on alluvial fans in the Canadian Rocky Mountains. Geological Society of America, Reviews in Engineering Geology, v. 7, 115-124.

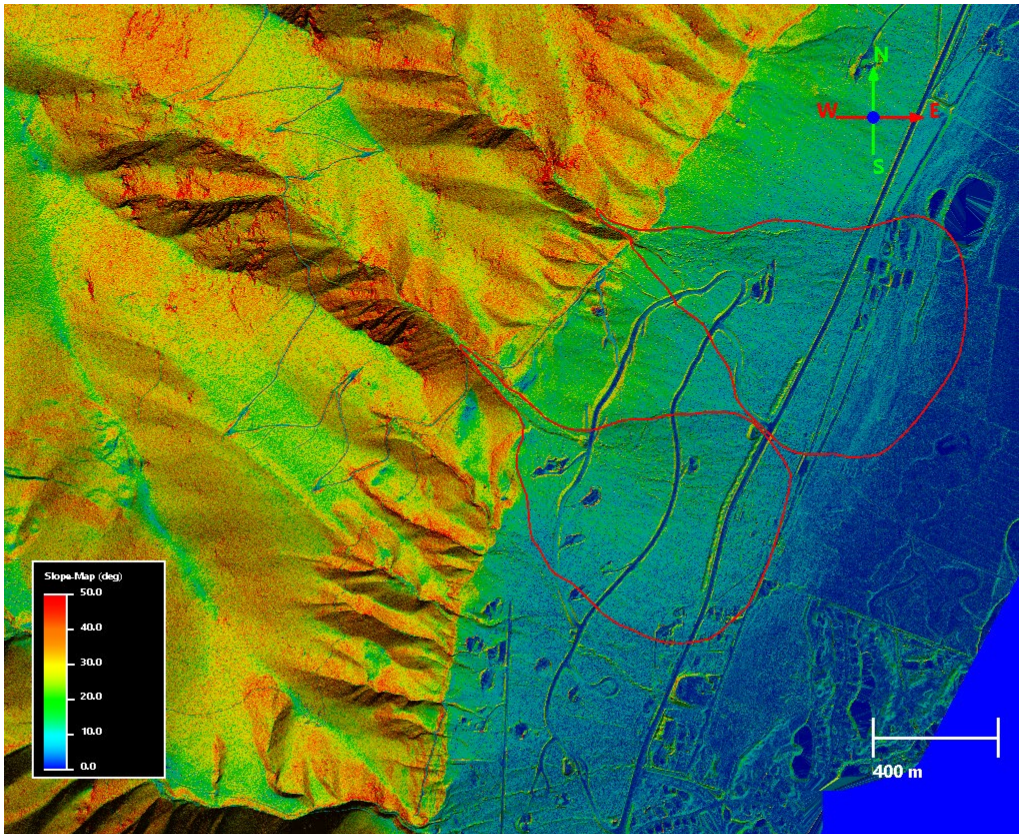
Pease, R.C., 1980. Geologic map, Genoa quadrangle [Nevada]. Reno, Nevada, Nevada Bureau of Mines and Geology, Urban Map Series, Genoa Folio, Map 1Cg, scale 1:24,000.

USACE, 2020. Carson River Watershed Alluvial Fan Inundation Mapping. Walla Walla, Washington. U.S. Army Corps of Engineers. Report prepared for the Carson Water Subconservancy District.

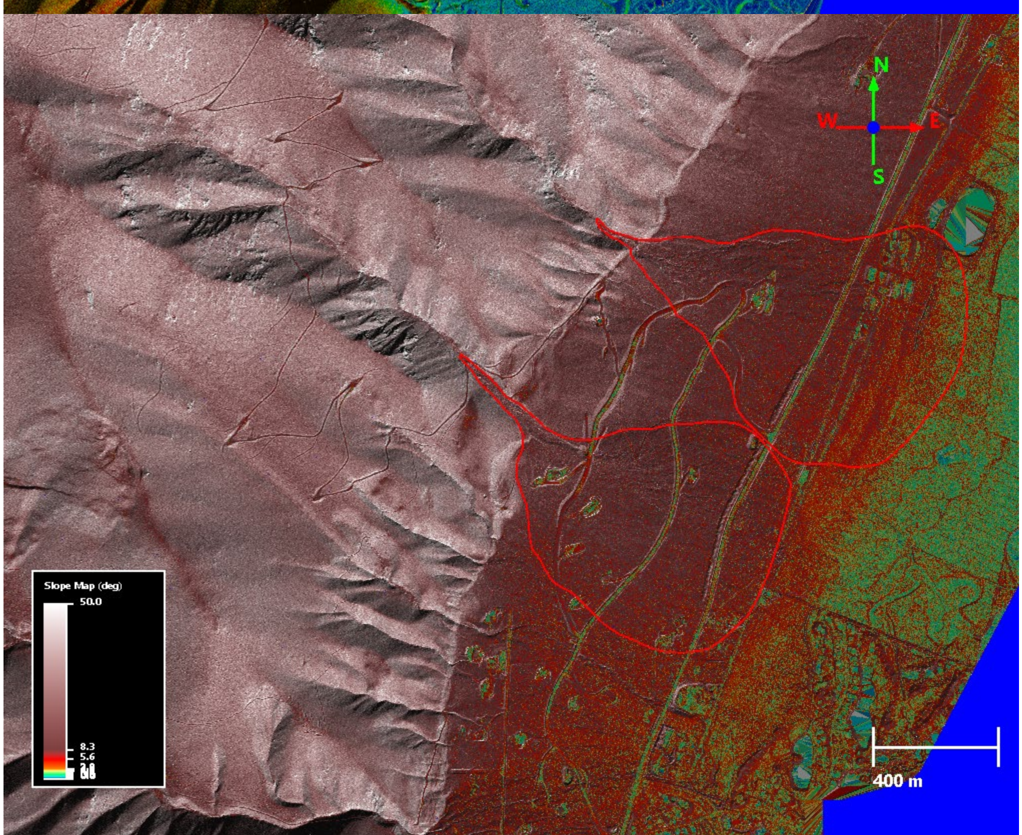
Appendix A

Slope maps
Fans 44 and 45
Genoa, NV

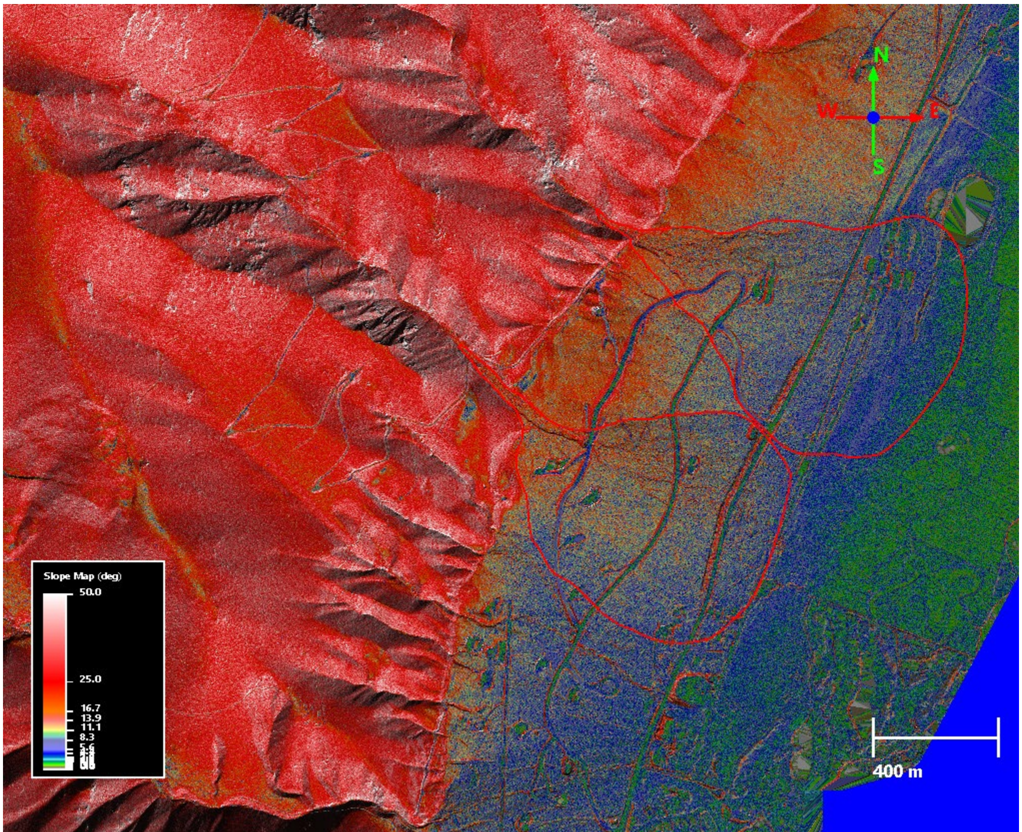
Slope: uniform gradient for slope angles 0 - 50°



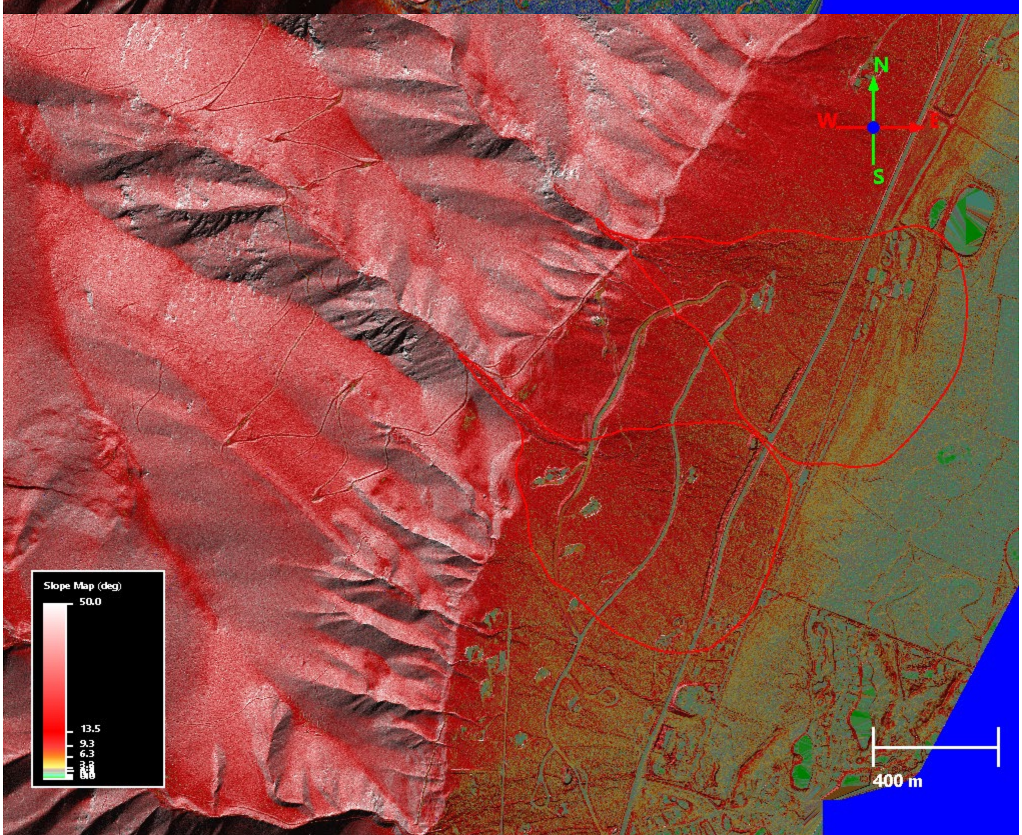
Slope Model 1: (0 - 50°)



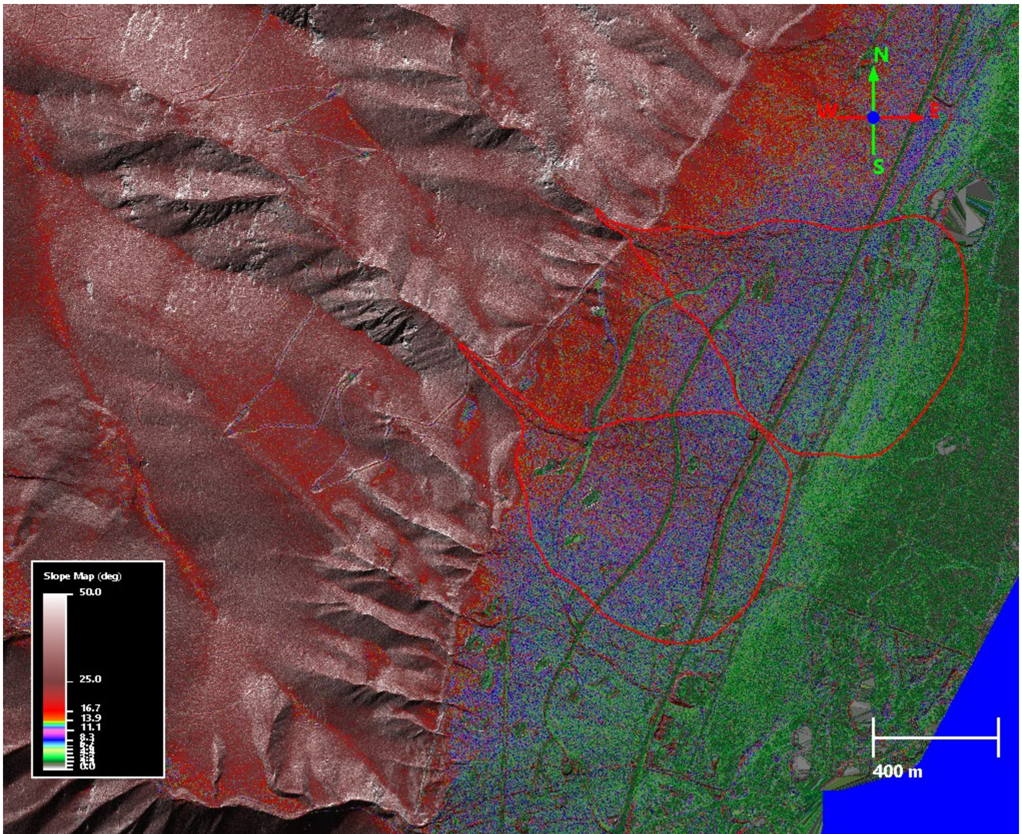
Slope Model 2:
(0 - 50°)



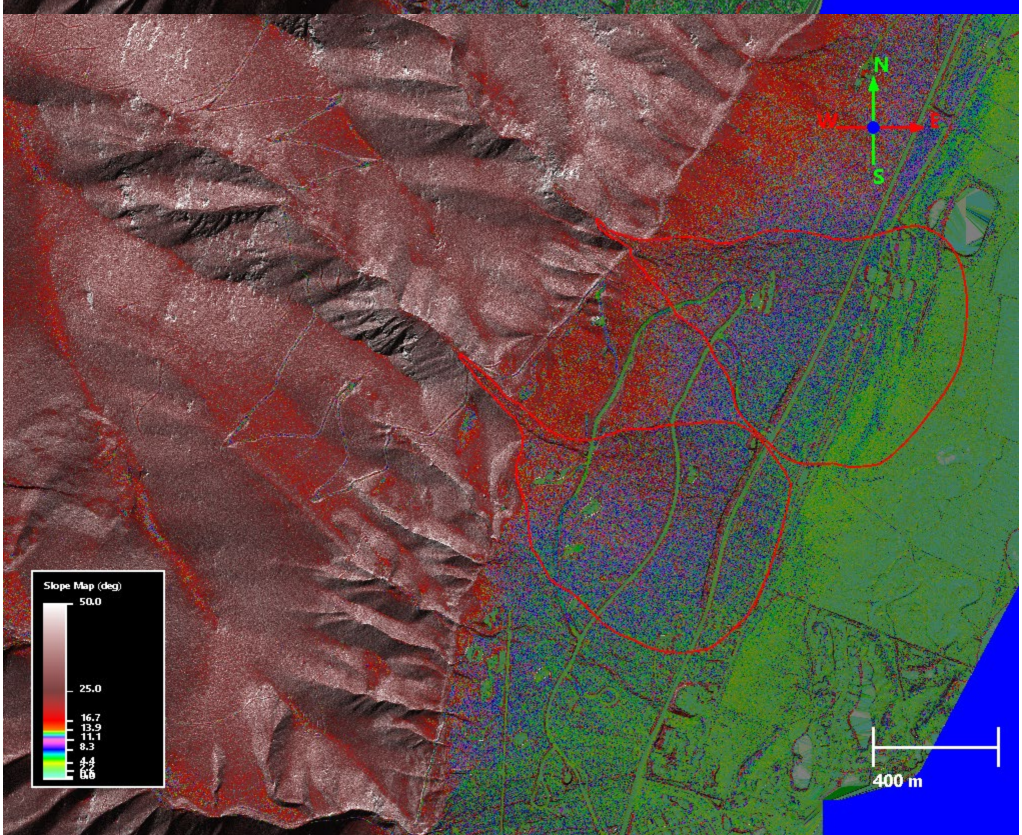
Slope Model 3:
(0 - 50°)



Slope Model 4:
(0 - 50°)



Slope Model 5:
(0 - 50°)



Slope Model 6:
(0 - 50°)