White Sands Missile Range Thurgood Canyon Watershed

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Abstract

The Thurgood Canyon alluvial fan, located on White Sands Missile Range (WSMR), is bisected by a primary installation road and is in the proximity of sensitive fish habitats. The intense, high energy flow events from arid mountainous environments and resulting large sediment loads create scour and deposition that can negatively impact drainage structures, the roads they protect, and local sensitive habitats and their species, especially those present on or near alluvial fans. This project was initiated to determine if/how sensitive fish habitats at the base of the Thurgood Canyon alluvial fan are impacted by the existing drainage infrastructure and to assess the condition and sustainability of the existing transportation infrastructure. Analysis of remotely sensed data was a primary method of assessing current conditions and historic changes of the alluvial fan due to the remoteness of the study sites and frequent inability to access the site due to military testing restrictions in the area. Using locally collected LiDAR data and aerial images from the USGS National Agricultural Imagery Program (NAIP), flow impacts and sediment depositions were mapped to determine current infrastructure conditions and develop more sustainable designs or management approaches. The location and pattern of sediment deposition, erosion, and channel formation over time along the lower reaches of the fan were also mapped to determine if the current drainage infrastructure or proposed changes to drainage infrastructure may increase (or mitigate) potential overland flow impacts to the sensitive habitat downstream. Findings show that the current drainage infrastructure maintains flow energy and sediment carrying capacity further down the fan than would occur in its absence. However, frequent to moderately rare (small to medium) flood events dissipate over 2 km from sensitive habitat and overland flow and sediment do not reach the base of the fan. Controlled flow diversion is recommended upstream of the primary installation road to mitigate both infrastructure and habitat impacts during very rare (very large) flood events.

Background

At White Sands Missile Range (WSMR), built infrastructure is located within and across active fluvial channels, which require either channelization or rerouting of the flow. The presence of transportation infrastructure can potentially alter the natural flow and sediment loads, creating conditions that might degrade the natural environment. Arid alluvial fans are episodic, changing little during dry or even average years, but producing tremendous geomorphological changes during large runoff events or wet years (MacArthur et al. 1990). Alluvial fans in arid environments are formed when sediment laden runoff from steep mountain sides drains onto a low-lying plain. As the channel slope becomes flatter on the adjacent plain, the flow loses a significant amount of energy, depositing the sediments that build up the fan (Blair and McPherson 1994). The overland flow that runs off the mountains are forced by orographic precipitation during the wet season, leading to extended dry periods punctuated by large discharges (Richards and Moore 2003).

The intense flow events within arid environments and resulting large sediment loads create scour and deposition that might negatively impact built infrastructure, especially those present on alluvial fans. Transportation infrastructure built on alluvial fans in arid regions are particularly at risk due to the steep slope of the fan, increased velocity and debris load of the flows, the unpredictable braided nature of the channels, and the unconsolidated (easily erodible) fan sediments. Access to infrastructure may be cut off during and following flow events due to flooding and damage These intense, short lived flood events pose a major safety hazard when trying to access infrastructure. Furthermore, the alteration of the local hydrology due to infrastructure can have a negative impact on local ecosystems within the alluvial fan including severe erosion, sediment deposition, and water quality degradation,

The only existing population of White Sands pupfish (*Cyprinodon tularosa*) lives within the White Sands Missile Range and the Holloman Air Force Base in southern New Mexico, primarily in springs and a stream located at the base of Thurgood Canyon's alluvial fan (Carman 2006). The pupfish was listed as a threatened species by the New Mexico State Game Commission in 1975. Although relatively plentiful where they occur, the pupfish are considered at risk because of their extremely limited distribution. Maintaining White Sands pupfish habitat, primarily the water sources that sustain them, is essential for their continued survival (Carman 2006). Primary threats include habitat alteration through construction or military training activities. The pupfish is protected by the Cooperative Agreement and Conservation Plan of 1994, which stipulates that the current population of the pupfish should be protected and measures be taken to increase their population.

Setting

WSMR is located partially within the Tularosa Basin of the Chihuahuan Desert, including the San Andres and Oscura Mountains that bound the basin to the west (

Figure 1). The region is arid and receives most of its annual precipitation from orographic precipitation during the North American Monsoon. As a result, numerous active alluvial fans are located within WSMR along the San Andres and Oscura Mountains.

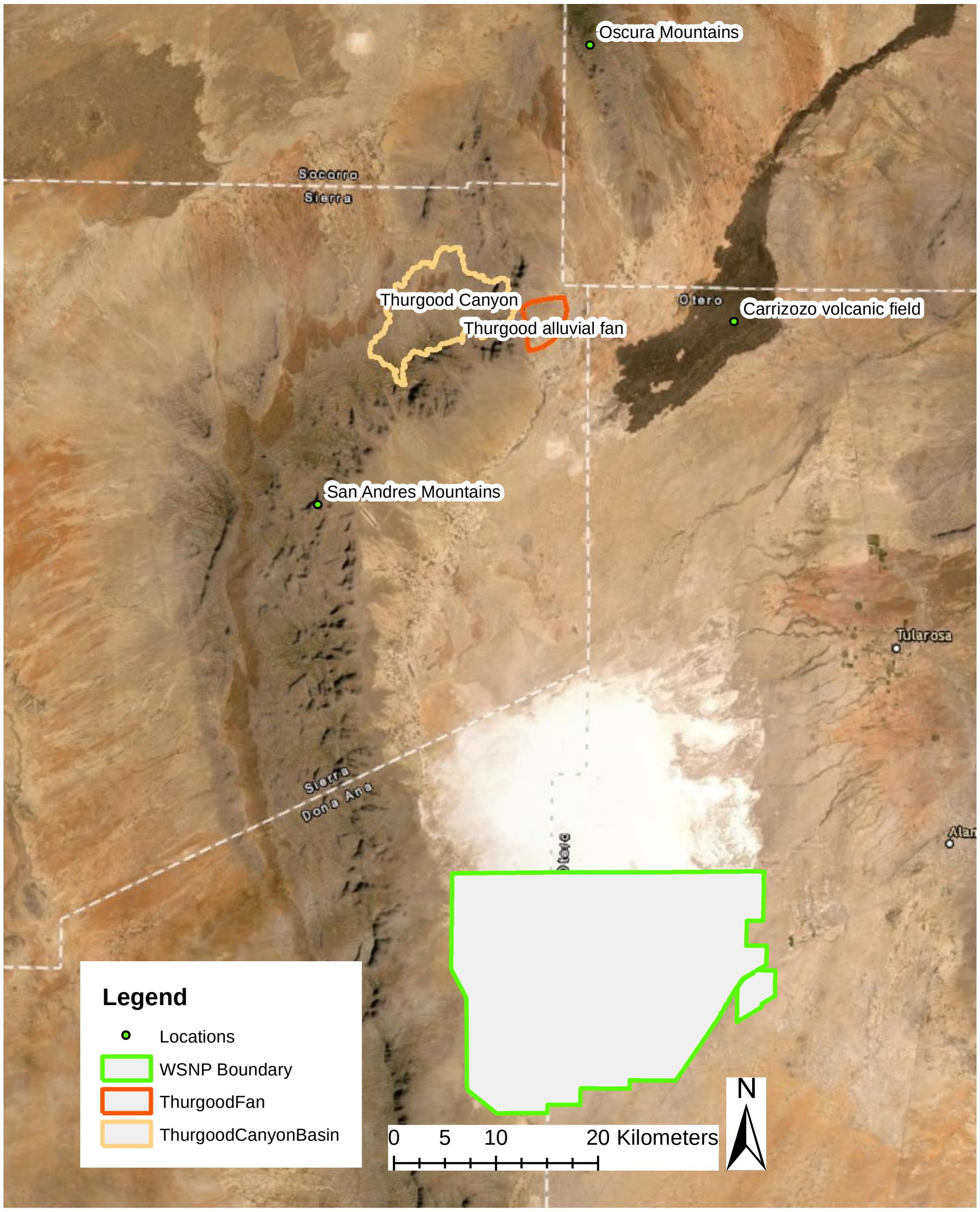

Figure 1. Overview of WSMR, Tularosa Basin, and White Sands National Park (WSNP) (NPS 2022. Public Domain).

The Thurgood Canyon basin covers 90.4 sq km (34.9 sq mi), drains to the east, and is located directly west of the Carrizozo volcanic field (Figure 1). The canyon mouth (and alluvial fan apex) rests between Sheep Mountain and Capital Peak. Thurgood Canyon basin receives 350.5 mm (13.8 in.) of precipitation a year (Waltemeyer 2001). The Thurgood Canyon valley contains sediment that ranges in size from silts to boulders, enabling large flow events to transport and deposit sediment onto the fan (Gomez-Viller and Garcia-Ruiz 2000). The Thurgood alluvial fan, located at the base of Thurgood Canyon, extends to the east and south, reaching almost to Salt Creek (Figure 2). The average slope of the fan is 0.017 m/m. The fan apex (top) rests at 1,360 meters, and the bottom at 1,275 meters. The fan length is approximately 4,700 m to the east and 5,300 m to the south. The fan is mostly gravelly sand with a portion of silty loam at the southern section. The primary US Department of Agriculture (USDA) soil types on the fan are the Queencreek, Mimvres, and Chilicotal complexes (USACE 2018). Parent material ranging in size from gravel to boulders is also found along the main channel. The area is well drained to excessively drained with a very low water table.

Salt Creek is east of Thurgood fan and drains to the south within a closed basin. Salt Creek runs into Big Salt Lake, where it becomes a salt flat during dry periods.

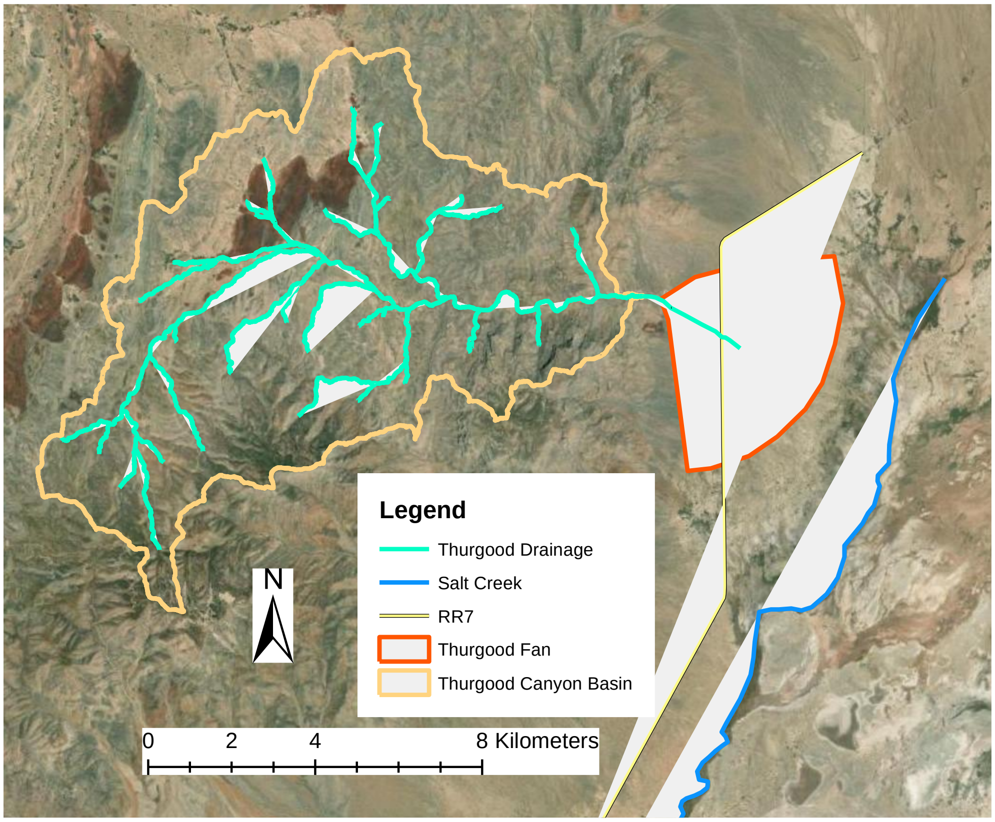

Figure 2. Thurgood Canyon basin boundary, alluvial fan, and surrounding area.

The Thurgood fan is traversed by Range Road 7 (RR7) 1,650 m downstream of the fan apex along the main drainage channel. RR7 is the primary north–south range road within WSMR on the east side of the San Andres (Figure 3). The road is impacted annually by seasonal flood events. Debris in the road presents a driving hazard, and closures can limit access to major portions of the range.

Several berms direct the main channel flow through the primary (#1) culvert structure under RR7. The primary berm is located on the south side of the main channel, beginning south of the fan apex and extending to RR7. Several other southerly berms direct surface runoff from the southern portion of the fan to smaller, secondary culverts under RR7 (culverts #2–5). Old channels south of the main channel (Figure 3) drain to the south and southeast and through these culverts. It is unknown if these culverts were designed and sized to provide local drainage for the southern portions of the alluvial fan or if they were sized to provide secondary drainage for flow coming from Thurgood Canyon.

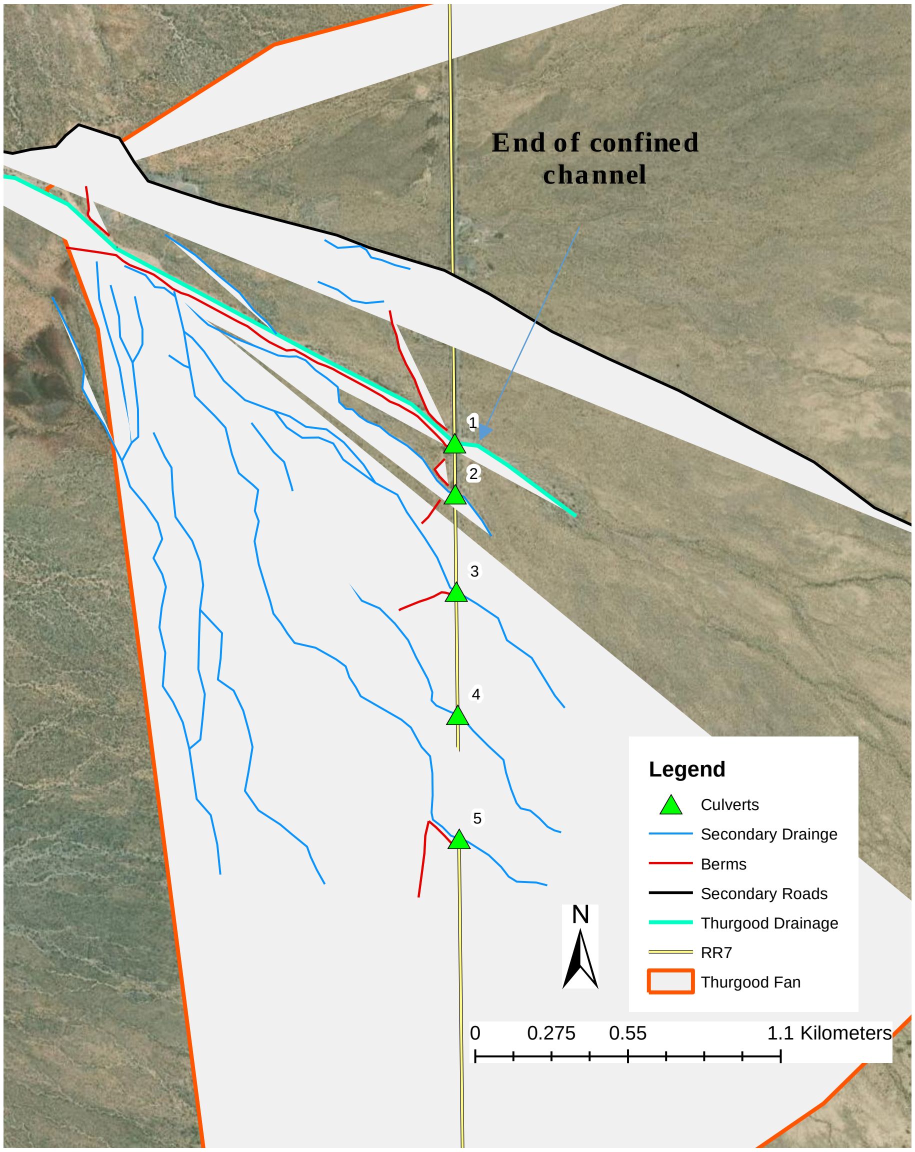

Figure 3. Thurgood Canyon alluvial fan detailing locations of RR7, flow diversion berms, and exiting drainage infrastructure.

The flow downstream of RR7 becomes unrestricted (Figure). The primary avulsion zone (where the confined channel ends) is approximately 475–500 m downstream of RR7. The avulsion zone is where surface flow begins to shift to new channel(s). These channel(s) change over time or from event to event, and the flow spreads out over a wider portion of the fan (Figure). The area downstream of the confined channel is also called the active lobe. The active lobe is where a large amount of deposition begins due to the energy lost by the flow as it spreads out over a wider area and into small channels. Further downstream, different portions of the runoff evaporate, infiltrate into the soil, or reach Salt Creek via surface or subsurface drainage. A major difference of the Thurgood fan from a typical active alluvial fan is that the flow diversion berms and the RR7 structure on the Thurgood fan constrain the main channel, causing the active lobe of the fan to be located east of RR7.

Figure 4. Avulsion zone downstream of RR7 looking upstream (*left*) and downstream (*right*).

Methods

Lidar and aerial imagery were used to assess scour, erosion, and deposition along the main drainage channel, south of the main channel, and downstream of RR7 over time. In particular, the area downstream of RR7 was analyzed where the avulsion zone begins and flows are no longer controlled. These areas were closely analyzed for trends in scour and deposition past the range road as well as determining if overland flows past the road infrastructure were reaching Salt Creek and potentially degrading its water quality.

Aerial images of the study site were reviewed, including images from October 1996, July 2005, January 2007, August 2009, October 2013, November 2017, and August 2019.

The WSMR Integrated Training Area Management Program (ITAM) office provided lidar collected in 2013. An additional lidar data set was obtained from the USGS 3D Elevation Program (3DEP) flown between late 2018 and early 2019. Site-specific lidar was also collected using an unmanned aerial system (UAS) mounted with a Geodetics GEO-MMS package with a Velodyne VLP-16 lidar. The Thurgood alluvial fan was flown March 2021. In addition, aerial images obtained by the USGS National Agricultural Imagery Program (NAIP) in 2011 and 2020 were used to assess changes to vegetation. Table 1 provides a summary of data sets, and Figure shows digital elevation model (DEM) data set coverage.

Table 1. GIS data sets.

Data Set	Time	Coverage	Native Resolution
WSMR Lidar	2013	Full Fan	75 cm
USGS Lidar	2019	Full Fan	1 m
Local Lidar	2021	Study Area Channel	75 cm
NAIP Aerial Image	2011	Full Fan	60 cm
NAIP Aerial Image	2020	Full Fan	1 m

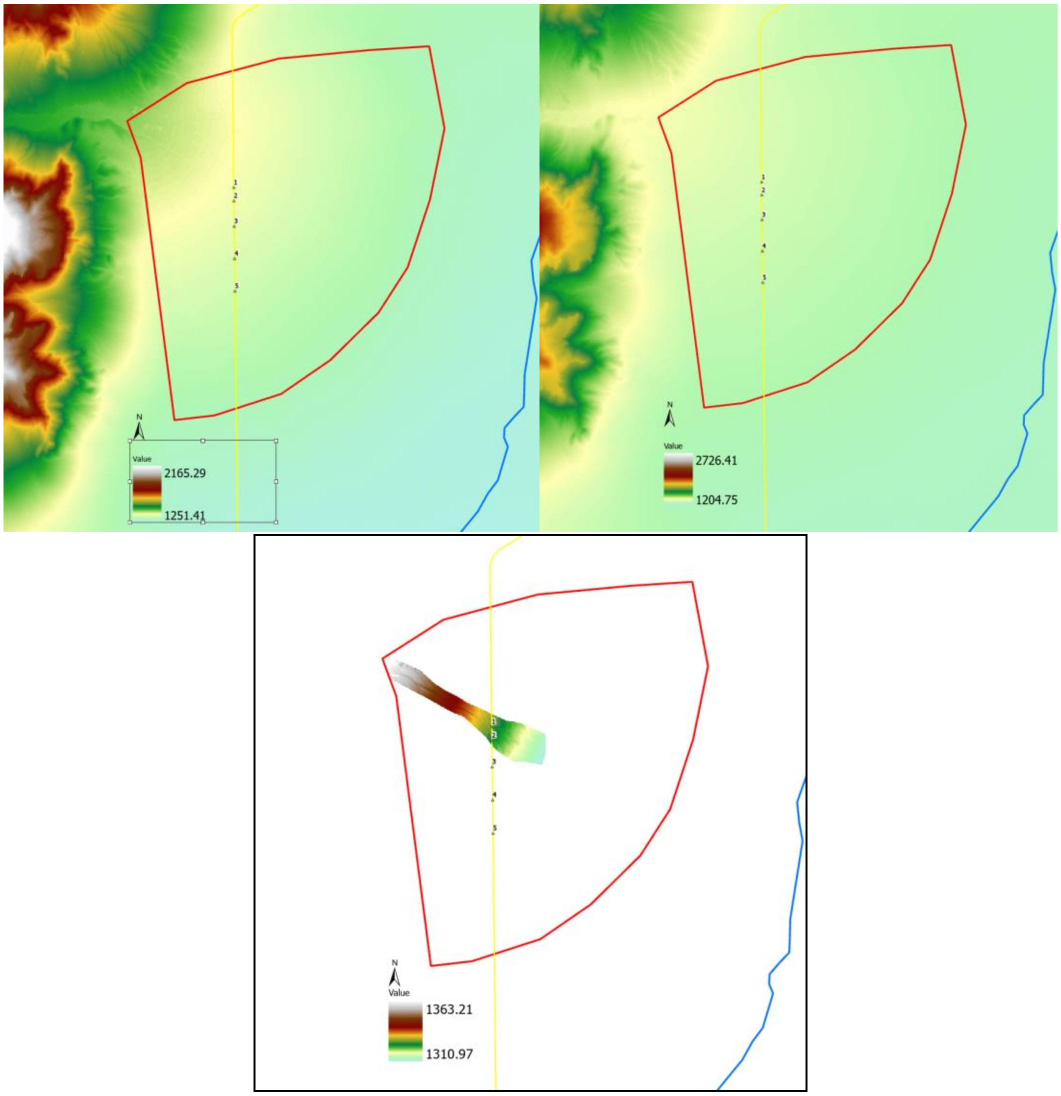

Figure 5. 2013 (*top left*), 2019 (*top right*), and 2021 (*bottom*) DEMs created from lidar.

DEMs were created from the collected LiDAR were used to assess the drainage patterns and subwatershed areas to the south of the main channel and west of RR7. The erosion and deposition that occurred between each of the collection years was mapped using the DEMs. Using ESRI ArcPro, the DEMs were resampled to ensure that they were on identical grids. The rasters were subtracted to find the elevation difference, creating a DEM, where positive and negative values indicate deposition and erosion, respectively. This process was completed between each temporally adjacent data set to determine the terrain changes over multiple time steps. The differences between DEMs show where new channels have formed or existing channels have evolved due to erosion and deposition caused by intermittent flow events. Each difference raster contains negative values where erosion occurred in red and positive values where deposition occurred in blue. Darker shades indicate a larger magnitude of erosion or deposition measured in meters of change. Values close to zero are white and indicate no change to terrain.

Changes in vegetation were analyzed using aerial images and used as a proxy to detect changes to the fan surface. Using the infrared (IR) band, the normalized difference vegetation index (*NDVI*) could be calculated for both years in ArcPro. NDVI is a dimensionless measure of the density of green in an image derived from the difference in near-infrared radiation (*NIR*) and visible red radiation (R) (Weier and Herring 2000).

$$NDVI = \frac{NIR - R}{NIR + R}$$

The values of NDVI range from -1 to 1, where values closest to 1 indicate the highest vegetation density, 0 indicates no vegetation, and values near -1 indicate disturbances like clouds or water. ArcPro adjusts the NDVI formula to create a range from 0 to 200 to fit into an 8-bit color ramp.

$$NDVI = \frac{NIR - R}{NIR + R} \times 100 + 100$$

Using the NDVI rasters created in ArcPro for the 2011 and 2020 imagery, the change in vegetation in that timeframe was determined. A cell-by-cell difference was calculated, which yielded a raster that shows where vegetation density decreased, indicating a loss of vegetation due to erosion undermining that area. The difference raster also shows where the density of vegetation increased, indicating healthy vegetation growth due to an increase in available water. This approach is limited in that it does not indicate erosion if vegetation was already absent in an area.

Results and Discussion

Downstream of RR7, the main drainage channel for Thurgood Canyon becomes unrestricted because the berms upstream of RR7 do not extend further east. The main channel remains channelized for about 500 m before bifurcating into smaller channels (Figure). This area is also characterized by a debris field of sediment, including sand, cobbles, and much larger particles. As the single, large channel begins to fan out into numerous channels, the flow loses sediment carrying capacity and the suspended sediment falls out of the flow and deposits in this area. These significant sediment deposits cause preferred flow paths (channels) in this area to change from flow event to flow event. New channels can be scoured out, while channels utilized during the previous event can be filled back in.

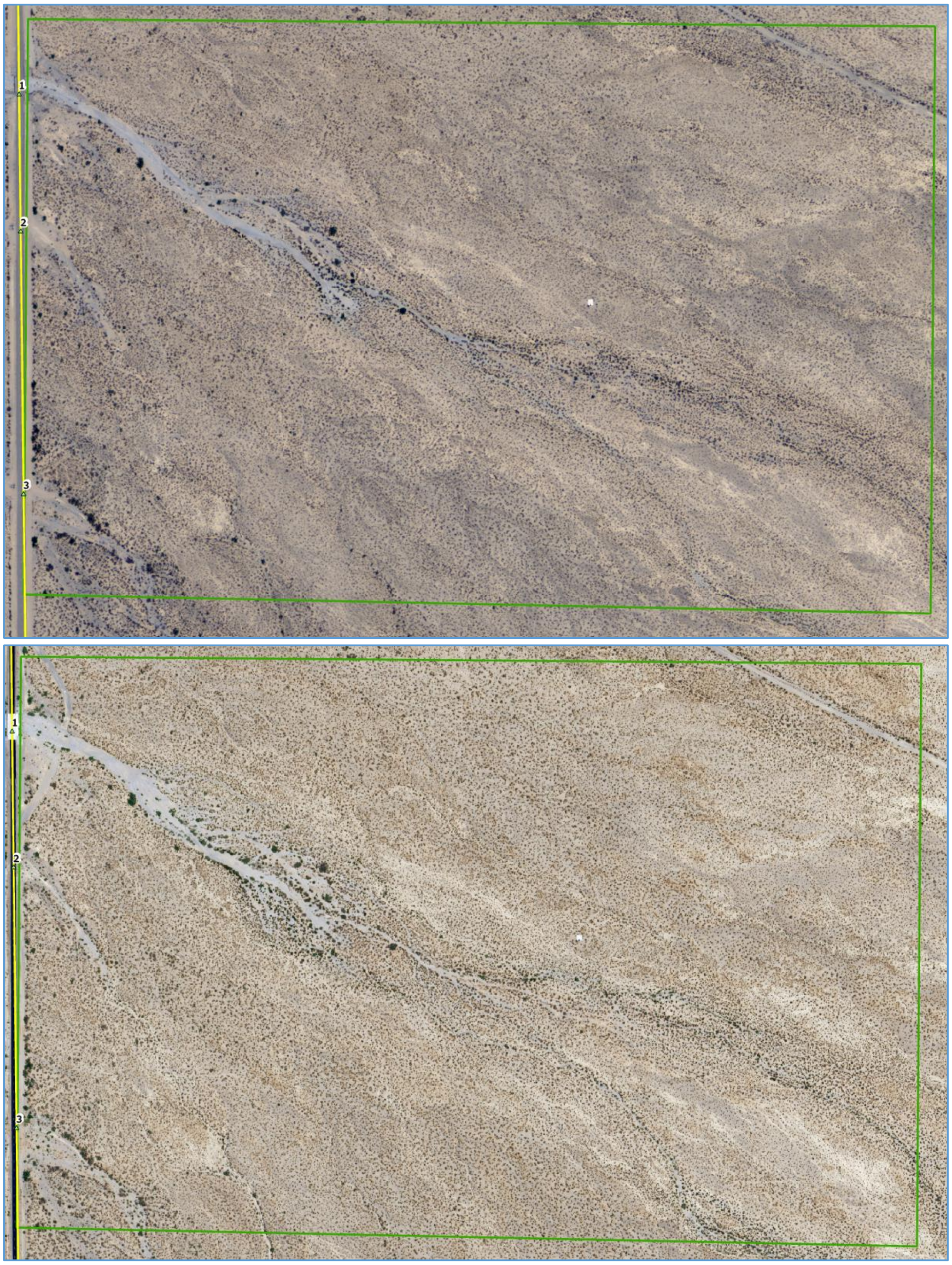

Figure 6. 2011 (*top*) and 2019 (*bottom*) aerial photos just downstream of RR7 (*green box* in Figure 25).

Downstream of the RR7 box culvert, there is a moderate amount of deposition seen in the main channel before flow spreads into numerous smaller channels downstream (Figure 4). The areas of deposition and the preferred flow path (channel) development can be seen over the two periods. Minor flows through the channels causes deposition in some old channels, while major flows cause the water to travel much further southeast and create or enlarge new channels. As noted above, these overland channels do not extend more the 3 km downstream of RR7.

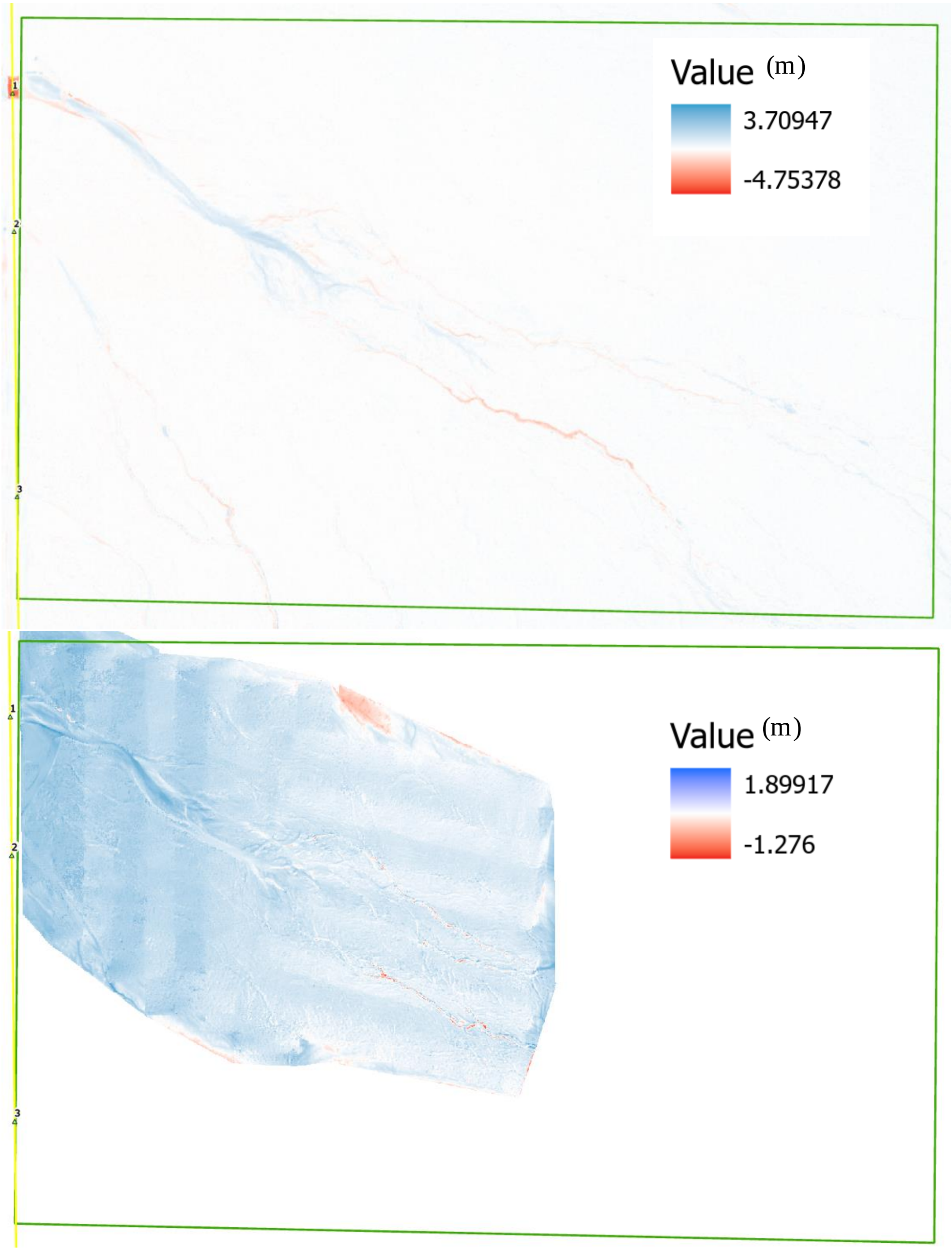

Figure 4. 2019 DEM minus 2013 DEM (*top*) and 2021 DEM minus 2019 DEM (*bottom*) just downstream of RR7 (*green box* in Figure 25).

The NDVI analysis reveals a similar trend of deposition immediately after RR7 where the abundance of moisture and new sediment promotes vegetation establishment and healthy growth. Some scouring and channel formation starting approximately 400 m downstream of RR7 are seen as reflected by the loss of vegetation along scoured channel banks (Figure). There is an increase of vegetation where water is plentiful, and erosion is observed to be low after the road. Channels of *red* with *green* edges appear further downstream indicating erosion of channels and water availability to foster vegetation growth at the edges of those channels.

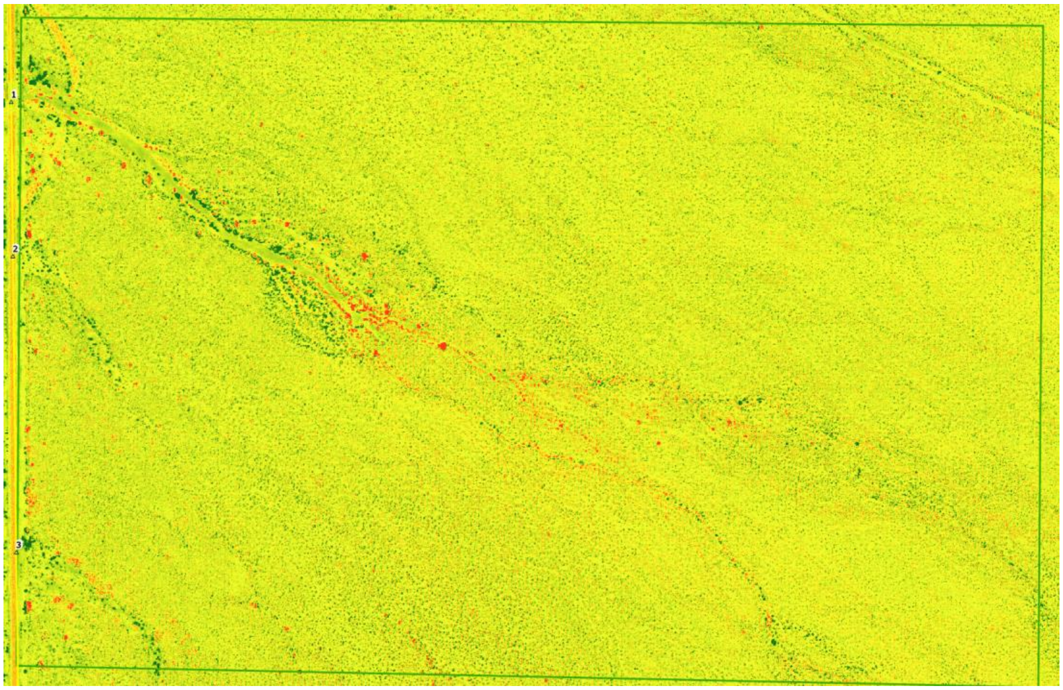

Figure 8. NDVI difference between 2020 and 2011 just downstream of RR7 (*green box* in Figure 25).

Conclusions

Overland flow conditions and paths on alluvial fans are unpredictable and can be extreme under the right conditions. Introducing built infrastructure into these environments can further exacerbate the intensity and unpredictability of flood events. Understanding and mapping flow paths in these situations can help infrastructure design decisions as well as reduce risk of adverse environmental impacts to the surrounding ecosystem. Using remote sensed data such as LiDAR and aerial imagery can reveal flow paths in an alluvial fan and reveal trends in extreme erosion and sedimentation. This method can help visualize the fans footprint, giving a clearer image of where and how far overland flows spread.

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