FINAL REPORT

2023-2024 Hutchins Water Center Student Research Grant

***KennaLee S. Worster**, Geology Program, Dept. of Physical & Environmental Sciences*
Gregory S. Baker, PhD, Research Advisor

Application of RGB and multispectral drone (sUAS) photogrammetry of alluvial fans in the Grand Valley of Colorado USA for detecting shallowly-buried channel features that may act as groundwater conduits

* Note: This research (Worster and Baker, 2023) was presented at the national Geological Society of America conference and the work received 1st Place Undergraduate Poster Competition honors from the Hydrogeology Division, (Pittsburgh, PA, October 2023).

SUMMARY

Identifying shallow subsurface pathways of groundwater within alluvial fans is important for both fresh- and contaminated-water studies. Application of drone (sUAS) technologies can provide additional insights. Drone flights were conducted with a DJI Phantom 4 Pro V2 drone with a 20-megapixel RGB camera (for DEM analysis) and a DJI Phantom 4 RTK Multispectral drone with 2-megapixel RGB, blue, green, red, red edge, and near infrared (NIR) cameras. The data were postprocessed using Agisoft Metashape Pro. Band-mixing results of the multispectral imagery, primarily through normalized-residual-differencing of selected bands, were compared to identify the clearest arrangement for highlighting surface reflectivity variations. At the test site, differencing the Blue and NIR bands $(Blue-NIR)^2 / (Blue+NIR)^2$ yielded the best expression of surface reflectivity variations hypothesized as a proxy for shallow (<1m) subsurface sedimentological variations.

BACKGROUND

Understanding the characteristics and behavior of paleochannels is essential for effective groundwater management and conservation efforts, and are especially critical in semi-arid environments such as the Grand Valley of the Western Slope of Colorado. Paleochannels in alluvial fans are important for groundwater for several reasons:

Water Storage: Paleochannels are typically composed of coarse-grained sediments like sand and gravel, which have high porosity and permeability. This means they can store significant amounts of groundwater, acting as natural reservoirs.

Groundwater Recharge: Alluvial fans often receive runoff from nearby mountains or hills during periods of intense rainfall or snowmelt. This water infiltrates through the sediments and recharges the groundwater aquifers within the paleochannels. This process is crucial for replenishing groundwater resources, especially in arid and semi-arid regions.

Groundwater Flow Paths: Paleochannels can act as preferential flow paths for groundwater, allowing it to move more freely through the subsurface. This facilitates the movement of groundwater from areas of recharge to areas of discharge, influencing the overall hydrological dynamics of the region.

Water Quality: The sediments within paleochannels can act as natural filters, removing impurities and contaminants from infiltrating water. This natural filtration process can improve the quality of groundwater stored within the paleochannels, making it suitable for various uses such as drinking water supply and irrigation.

Ecological Importance: Groundwater stored within paleochannels can support unique ecosystems, providing habitat and water sources for various plant and animal species. These ecosystems may rely on the consistent flow of groundwater from paleochannels to maintain their biodiversity and ecological functions.

The identification of paleochannels is critical in clean and contaminated water studies. The sites in and around the Grand Valley along the Western Slope of Colorado represent the leading edge of water-related research in high altitude semi-arid environments. The result of this project may be applicable to similar sites in similar areas, as well as possibly expanded to other climates and elevations with similar shallowly-buried groundwater pathways.

Drilling and geophysical methods, such as ground penetrating radar (GPR; Bennett et. al, 2006) are traditional techniques for mapping paleochannels (*Figs. 1-2*). However, these techniques are invasive and time/resource consuming. The proposed research is focus on testing the hypothesis that multispectral drone (sUAS) imaging can also be used to detect shallowly-buried paleochannels, for less resources.

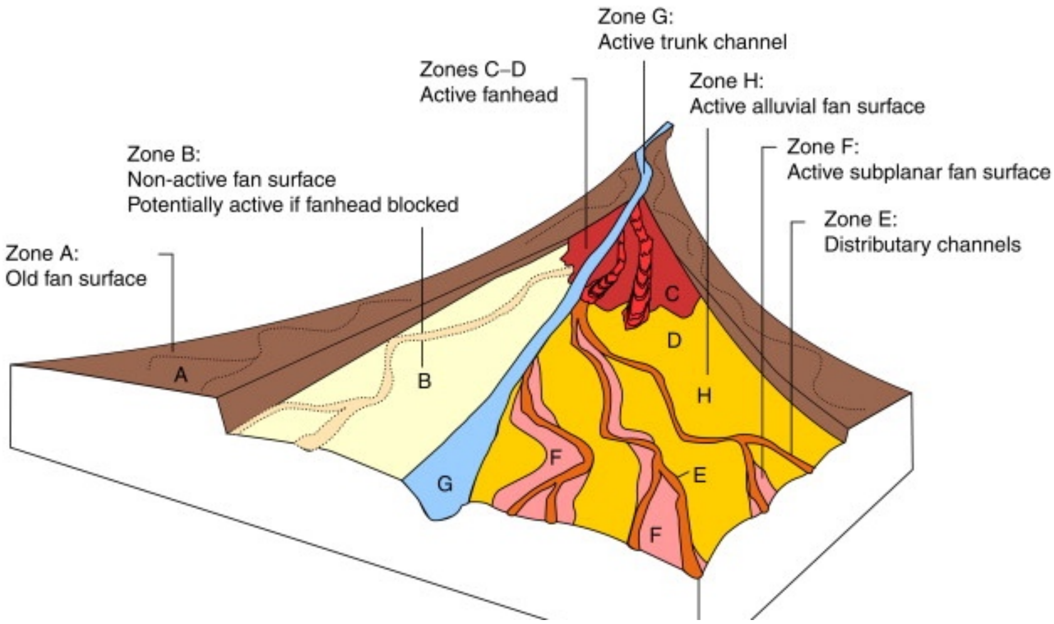

Figure 1. Typical alluvial fan geometry (modified from NRC, 1996).

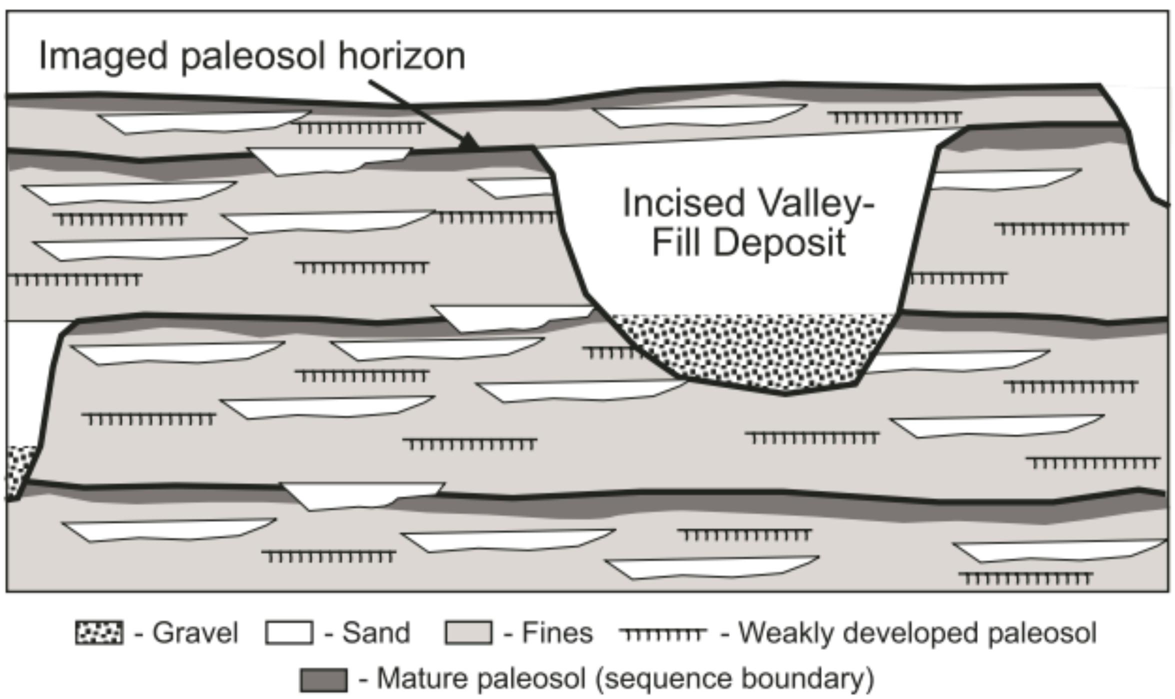

Figure 2. Schematic cross-sectional geometry of an alluvial fan (modified from Benett et al., 2006). Vegetation may take advantage of the variations in porosity that act as a proxy.

METHODS

Hardware & Software

Hardware for data acquisition included two DJI Phantom drones: a DJI Phantom 4 Pro V2 with a single 2.54cm CMOS sensor (20 MP) in RGB (owned by GeoAvatar LLC), and a DJI Phantom Multispectral, with six 0.88 cm CMOS sensors (2MP) in RGB, 450nm, 560nm, 650nm, 730nm, and 840 nm (owned by CMU).

Software included DroneDeploy v 2.202.0 to create automated flight geometry and preliminary stricture-from-motion (SfM) models & orthophotos, while Agisoft Metashape Pro version 2.0.1 will be used to create more robust SfM models & orthoimages (RGB and multispectral). In addition, Microsoft Excel with the Analysis ToolPak was used to perform statistical analyses.

Data Acquisition

Drone flights were conducted (*Figs 3-6*) with a DJI Phantom 4 Pro V2 drone with a 20-megapixel RGB camera (for DEM analysis) and a DJI Phantom 4 RTK Multispectral drone with 2-megapixel RGB, blue, green, red, red edge, and near infrared (NIR) cameras.

Paleochannels were discovered correlating with Locations F and D on Figure 7, and field observations (shown in *Figs. A-F*) were recorded where potential exposures of At the exposures weathered Mancos Fm (Q_{wm}), alluvium (Q_a), and loess (Q_l) were present overlying competent Mancos Fm (K_m) approximately 10 meters downgradient at Location D and 5 meters down gradient at Location F. Locations D and F show little to no surface channel expression of water in the 0.5-m contours (from the RGB drone SfM model).

Expression of potential shallow paleochannels were examined instead by using multispectral imagery and generating visualizations of different combinations of bands (Blue, Green, Red, Red Edge, and Near Infrared). Greatest image contrasts for paleochannel expressions were found in normalized residual differencing of the blue and NIR bands, $(\text{Blue-NIR})^2 / (\text{Blue+NIR})^2$. Images were analyzed for distributaries of the main paleochannel which was estimated from vegetation. Estimated location of the main paleochannel is where there are greasewoods instead of drought resistant grass and salt brush.

Orthomosaic (*Fig. 7*) shows areas where alluvium (Location B) is grey shades and areas where loess (Location C) is in a brown color. Lithology interpretations are overlayed on the multispectral images (*Figs. 8 and 9*) based on the reflectivity of the units with field checking. The reflectivity given by the multispectral images is a proxy for the sediment type (Q_a or Q_l) and used to determine potential paleochannels locations.

Figure 3. Map of Colorado, USA showing the field site at the Grand Mesa-Whitewater alluvial fan system (yellow star). From Google Earth, 2023.

Figure 4. Map of western Colorado annotated to show Grand Valley and Grand Mesa, with the test site in the Grand Mesa-Whitewater alluvial fan system (yellow star). From Google Earth, 2023.

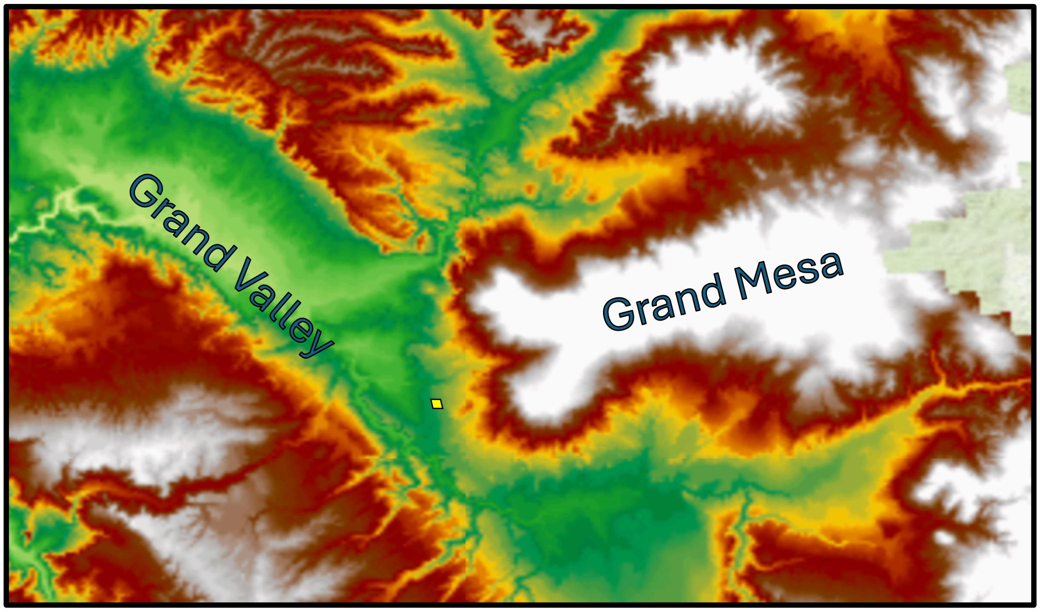

Figure 5. Digital elevation model (DEM) of the region (USGS), highlighting the Grand Mesa source for the alluvial fan apron, including the test site.

Figure 6. Google Earth imagery of the field site, outlined in yellow. The main paleo-alluvial drainage is from the northeast to southwest.

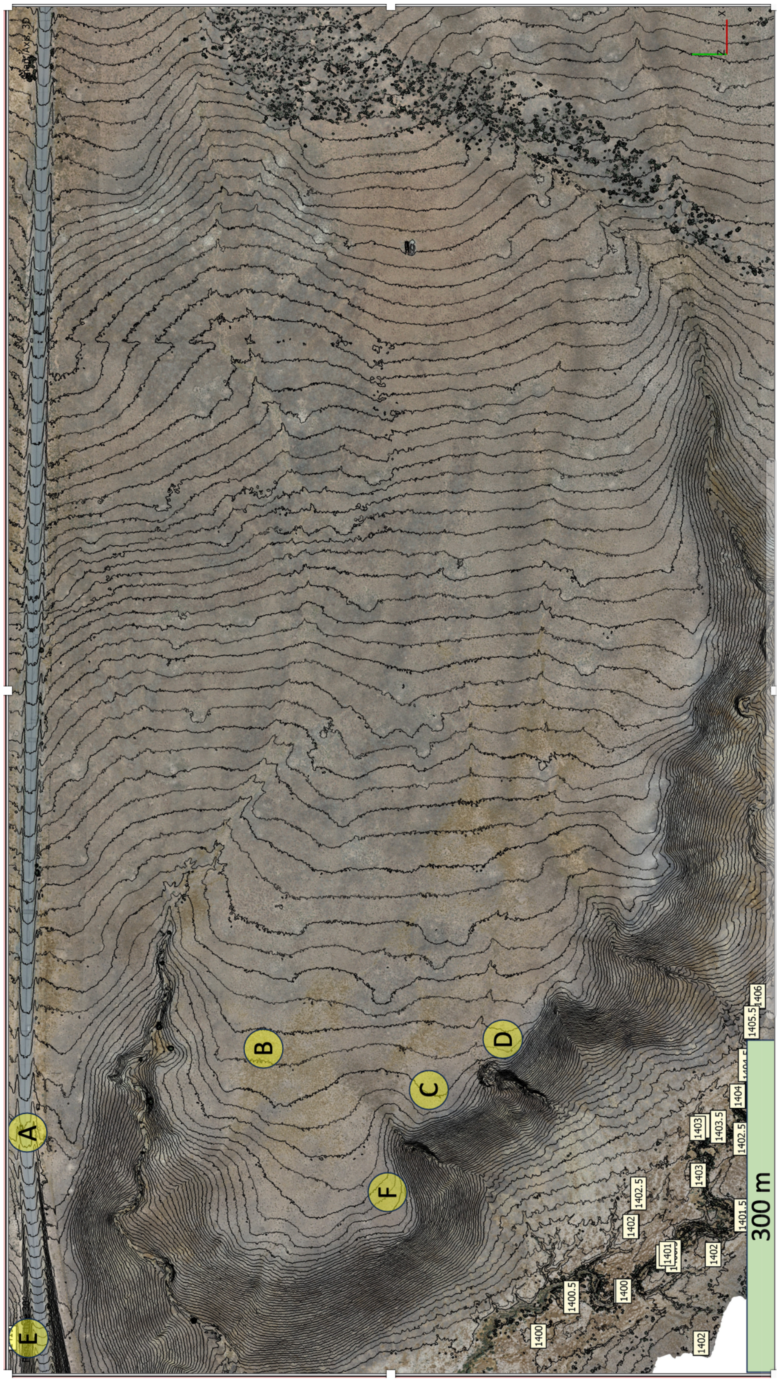

Figure 7. High-resolution (2.5 cm/pixel) orthomosaic of the test site generated from >2000 images collected using a DJI Phantom 4 Pro V2 drone with a 20-megapixel RGB camera (acquisition time approximately 3 hours while flying at 12mph at 300 ft AGL). A structure-from-motion (SFM) analysis was used to generate a DEM (<5 cm/pixel). The contour lines added are at 0.5-meter intervals. The contour lines show surface expressions which can be differentiated from subsurface expressions found on the images from the multispectral drone. Locations of close-up hand-held camera images described in Figures A-D are shown to emphasize the lack of major channeling in the central part of the fan lobe.

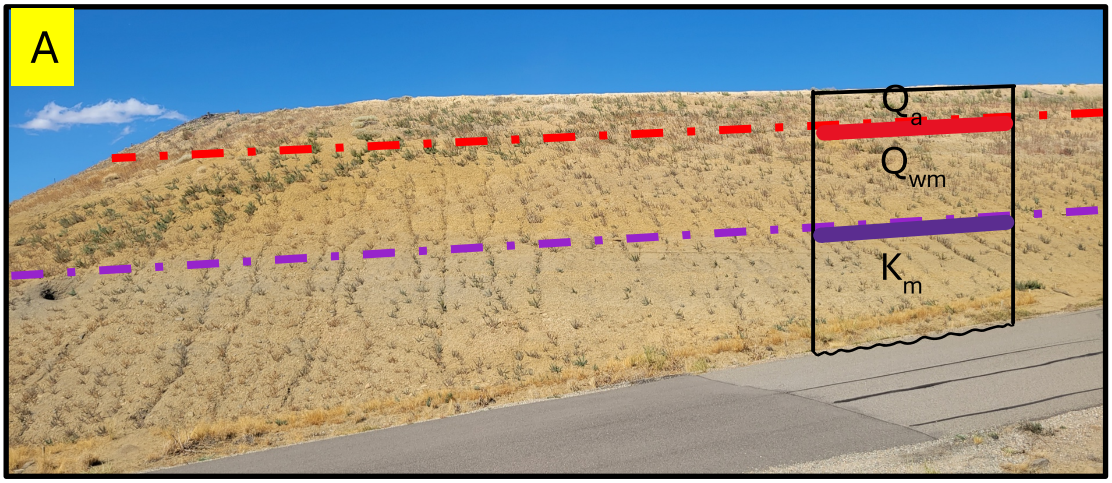

Figure A. Shallow stratigraphy at the test site. The distinct contact between competent Mancos Fm (K_m) and weathered Mancos Fm (Q_{wm}) is shown in purple, easily identified in the field by color. The contact between Q_{wm} and alluvium (Q_a) is in shown red.

Figure B. Alluvium (Q_a) was identified on the surface throughout the site. There was a notable difference in vegetation and compaction on the alluvium vs the loess. The alluvium has drought resistant grasses and is more consolidated than the loess which grows salt brush.

Figure C. Loess (Q_l) was found on the surface throughout the site as a patchy, thin (<0.25m) veneer. At the site, the likely loess source is the Canyonlands region of eastern Utah. The reddish color of the loess and fine grain size is a distinguishing characteristic.

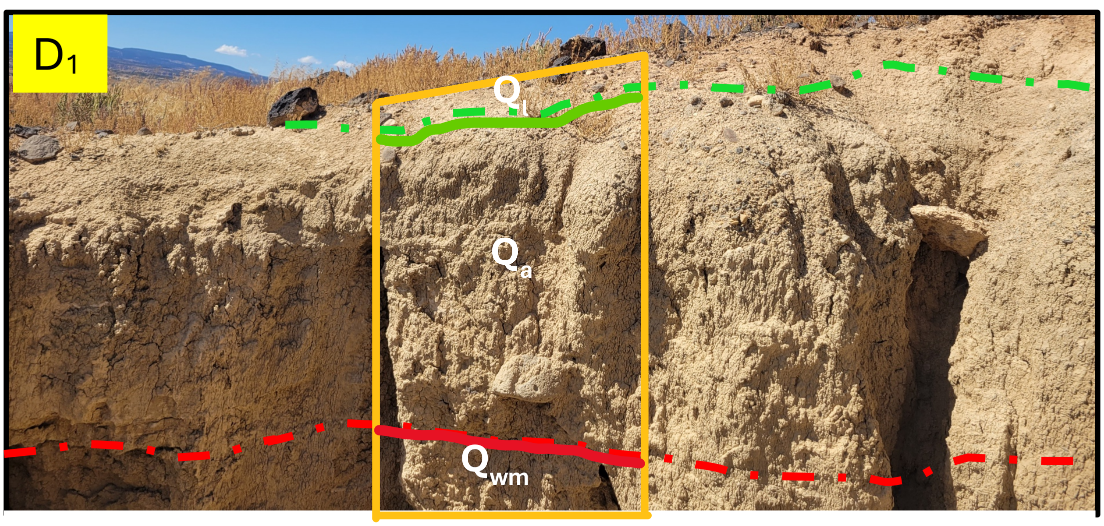

Figure D_1. This outcrop was found along the escarpment of the alluvial fan system between stations C and F. The weathered Mancos Shale (Q_{wm}) and alluvium (Q_a) contact is shown with in red. The alluvium and loess (Q_l) contact is shown in green.

Figure D_2. Gravels found within the alluvium (Q_a) at the potential paleochannel exposure were found while hiking the study area. The red silt sized sediments seen above and to the left of the gravels are loess (Q_l).

Figure D_3. Loess (Q_l), alluvium (Q_a), and weathered Mancos Fm (Q_{wm}) at an exposure of paleochannel deposits. Note the vegetation change from grass on the alluvium to salt brush on the loess.

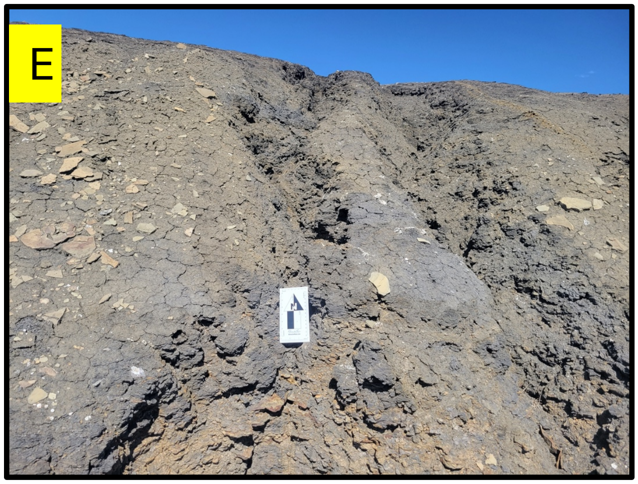

Figure E. Competent Mancos Fm (K_m) can be identified by its dark grey to black color, shallow marine fossils, and flakey properties consistent with shales. There are mud cracks and sheet like layering seen in this outcrop. The less weathering experienced by the Mancos, the darker it is in color.

Figure F. Weathered Mancos Fm (Q_{wm}) is highly friable, light brown color, but still produces some shallow marine fossils. The brown color indicative of clay weathering.

RESULTS

Figures 8 and 9 are two representations of the normalized residual differencing of the blue and NIR bands, $(\text{Blue-NIR})^2 / (\text{Blue+NIR})^2$ with superimposed DEM-contours at 0.5-m intervals. The top image (*Fig. 8*) is in greyscale (black is higher reflectivity) with the contours in light brown, while the bottom image (*Fig. 9*) is a heat map (with warm colors representing higher reflectivity) with 0.5-m contours in black. On the greyscale image the darkest areas highlight loess (Q_l ; *see Fig. C*) and narrow modern ephemeral surface-flow channels. More subtle moderate-reflectivity regions dominantly correlate with vegetation changes.

These subtle variations—not linked with Q_l or modern ephemeral channels—are hypothesized to correlate with vegetation changes as proxy for shallow grain-size-driven variations in hydraulic conductivity. Channel-like morphology of these features as well as a lack of relationship with surface drainage indicates a possible subsurface connection.

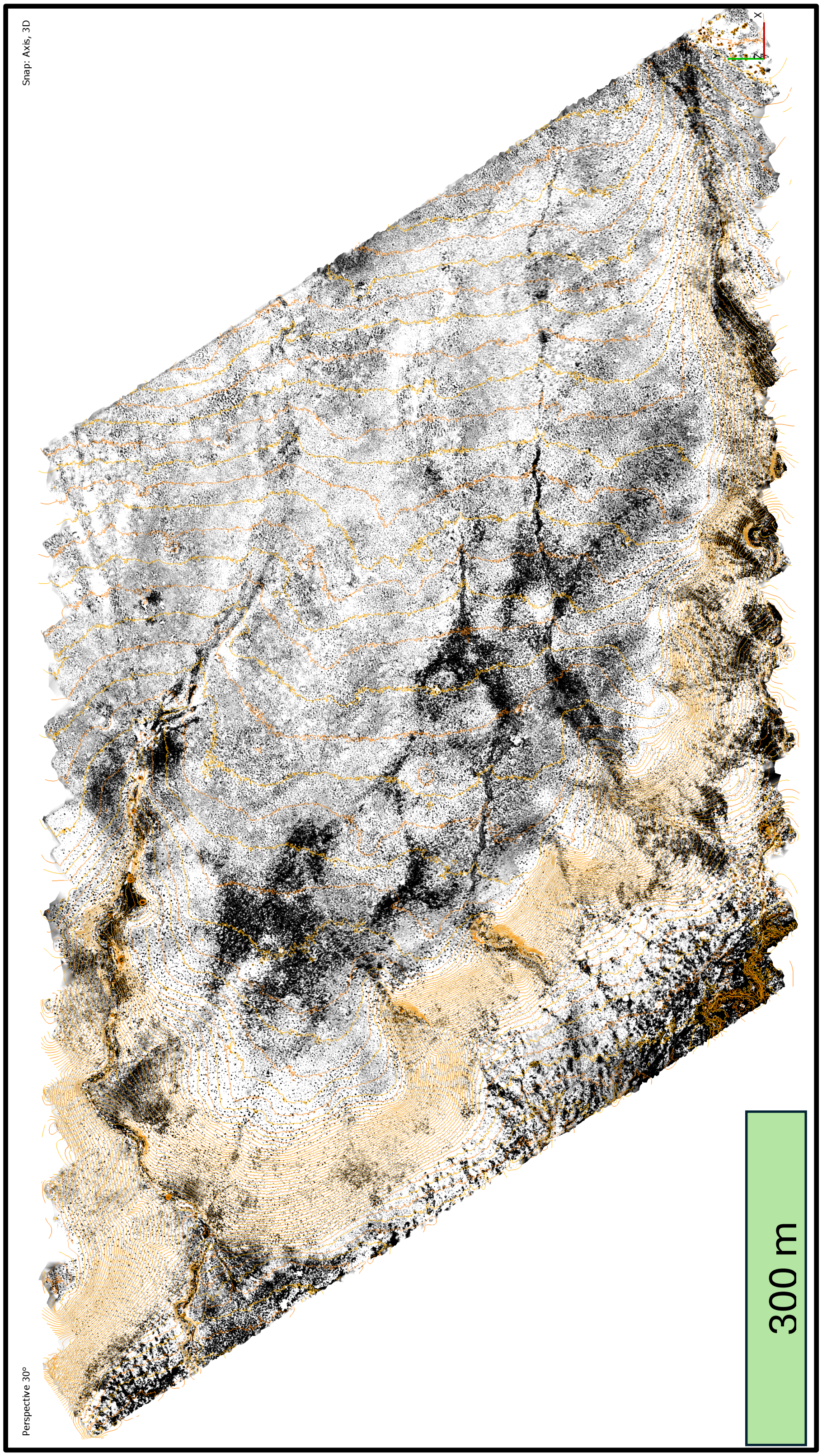

Figure 8. Multispectral normalized-residual differencing of blue & NIR difference model in greyscale (black is higher reflectivity) with 0.5-meter contour intervals in light brown.

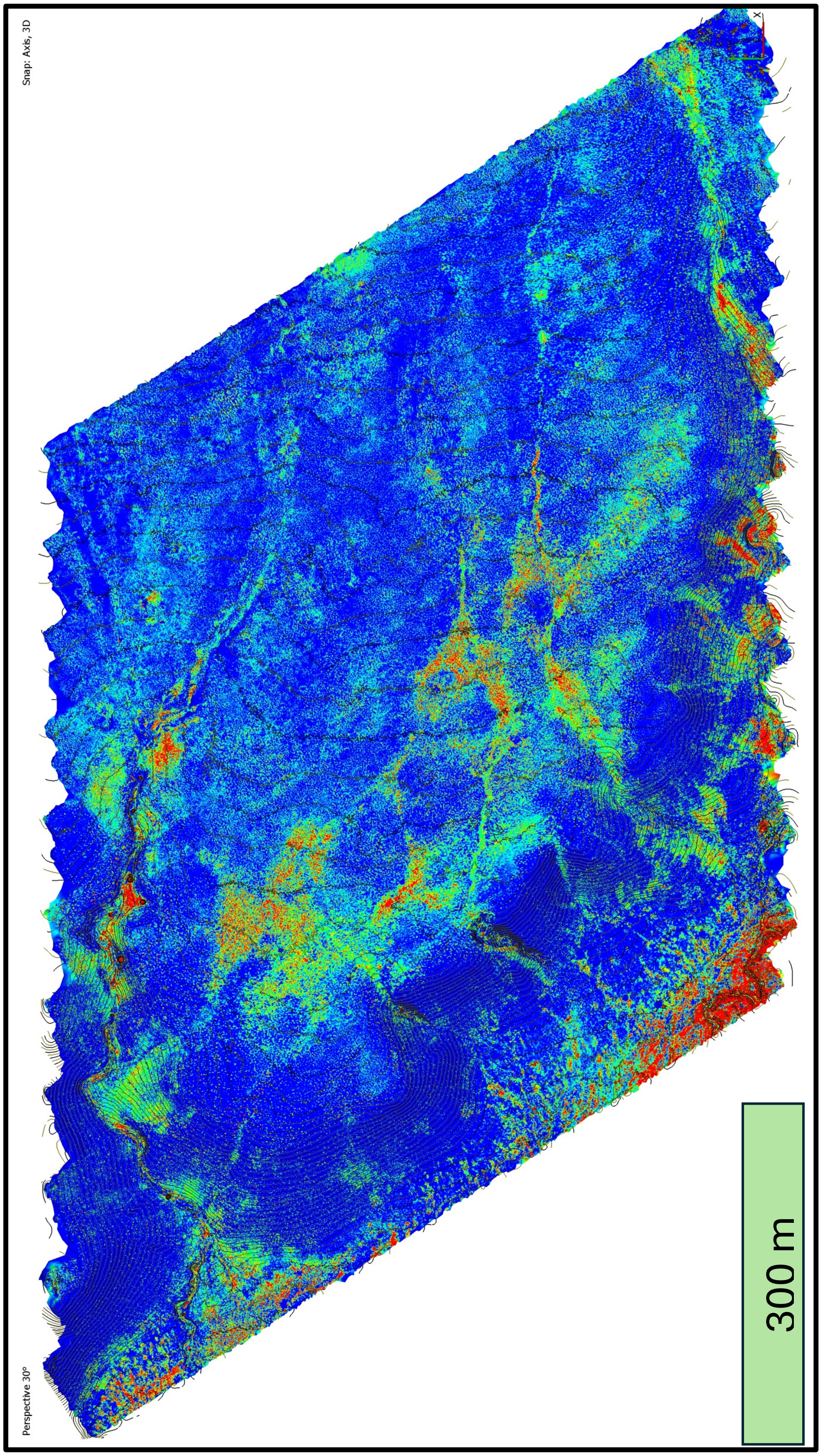

Figure 9. Multispectral normalized-residual differencing of blue & NIR bands shown in a heat scale (warmer colors higher reflectivity) with 0.5-meter contour intervals in black.

DISCUSSION

The preliminary site interpretations are shown in *Figure 10.* The integrated interpretation was created by correlating field data (*Figs. A-F*), high-resolution orthomosaic & DEM imagery (*Fig. 7*), and multispectral imagery (*Figs. 8 & 9*). The high reflectivity regions in the multispectral images (*Figs. 8 and 9*) correspond to Location C (*Fig. 7*) where the loess (Q_l) is identified, while the lower-reflectivity regions correspond to Location B (Fig. 7) where the alluvium (Q_a) is at the surface. Narrow, high reflectivity regions (*Figs. 8 & 9)* correlate with modern ephemeral channels. In Figure 10, alluvium is not labeled the image because it is present at the surface throughout most of the site.

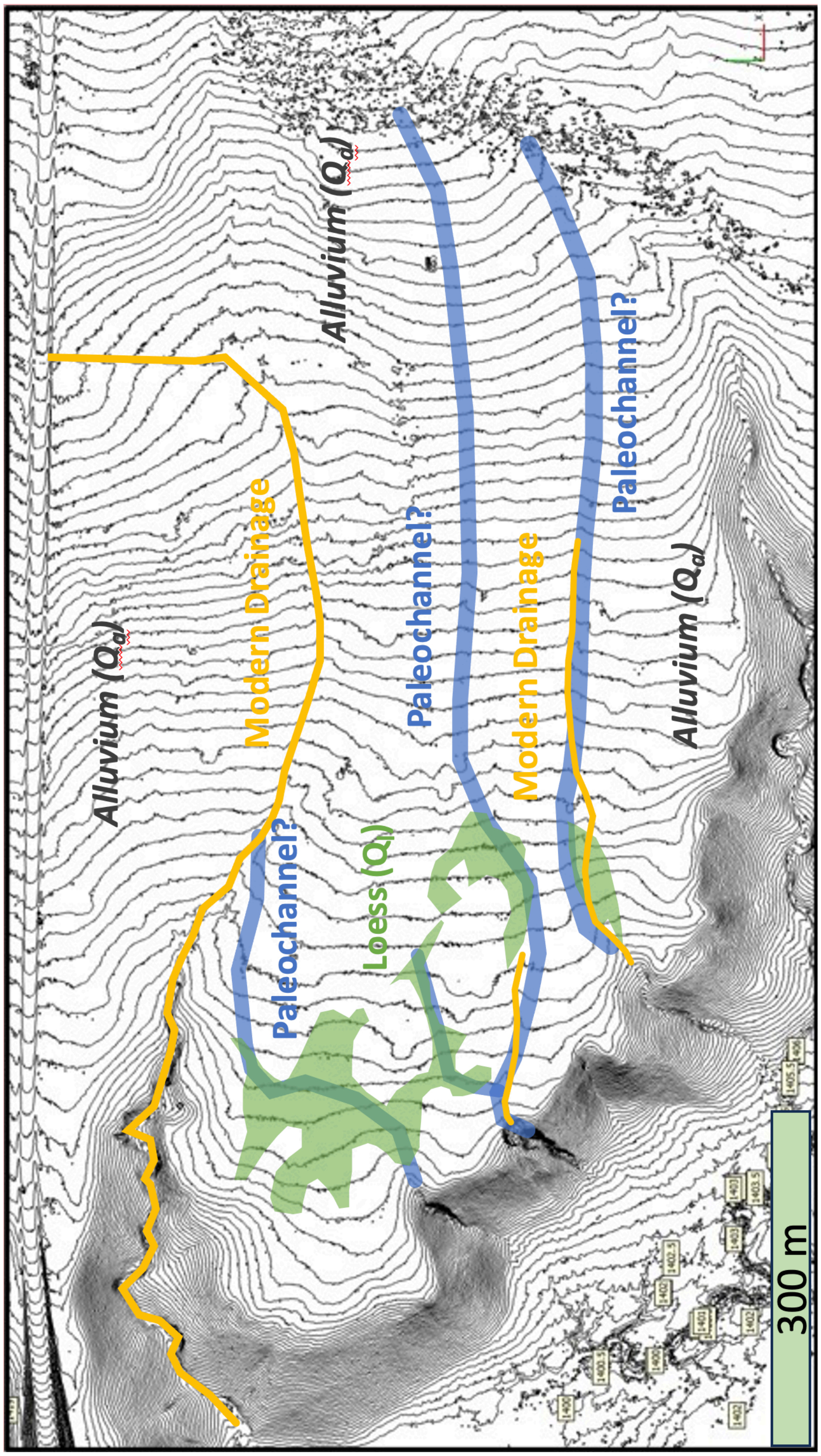

Figure 10. Preliminary site interpretation integrating field data, DEM, RGB images, and multispectral normalized-residual differenced images. Orange lines represent modern ephemeral channelized surface flow paths. Light green regions are loess (Q_l) patches. Blue lines represent hypothesized shallow paleochannels flow paths, dominantly based on vegetation as a proxy.

FUTURE WORK

Now that hypothetical locations of shallow paleochannels have been hypothesized, the next step will be to make field observations syn- and post-precipitation to analyze the patterns of overland sheet flow, channelized flow, shallow subsurface storm flow, and return flow. These flow patterns will then be correlated to the site sediment interpretations. A second step will be to sample geochemical characteristics (pH, electric conductivity, and the oxidation reduction potential) of rainwater before and after water has traveled through the site, to determine whether multiple pathways exist. A third step will be to generate a mass balance by setting up temporary notch weirs at the ephemeral surface channels (to quantify surface runoff) to be compared with correlated down-gradient weirs at the incised flow regions at the edges of the alluvial fan deposit (where there is hypothesized groundwater outflow).

Acknowledgments

This research was funded through a grant from the Ruth Powell Hutchins Water Center at Colorado Mesa University (#0002640). We want to thank Dr. Deborah Kennard professor of Environmental Sciences at CMU for assistance with plant identification, Dr. Mike Morse hydrogeologist for research connections, and Jim Garcia for access to the private property near the research site.

References

Bennett V, G.L., Weissman, G.S., Baker, G.S., Hyndman, D.W., Regional-scale assessment of a sequence-bounding paleosol on fluvial fans using ground-penetrating radar, eastern San Joaquin Valley, California: *GSA Bulletin*; May/June 2006; v. 118; no. 5/6; p. 724–732. doi: 10.1130/B25774.1

NRC (National Research Council), 1996. Alluvial Fan Flooding. National Academy Press, Washington, DC, 172 pp.

Worster, K. and Baker, G.S., 2023, Application of RGB and multispectral drone (sUAS) photogrammetry of alluvial fans in the Grand Valley of Colorado USA for detecting shallowly-buried channel features that may act as groundwater conduits: Geological Society of America Abstracts with Programs, Vol. 55, No. 6. doi: 10.1130/abs/2023AM-395359