Drainage Basin and Fan Relationship in the Spring Mountains, Nevada

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Introduction

Snow peaks amaze viewers on warm days in the Las Vegas valley. Once melted, water will create run-off and transport rocks and sediment down towards the base of the mountain. This fluvial example exhibits one of many factors that produced alluvial fans surrounding the Las Vegas valley. An overview image of the surrounding area around Las Vegas will contain varying shapes and sizes of alluvial fan distribution. I intend to record the area of both the drainage basin and the alluvial fan below the basin, a relationship I will refer to as the basin to fan ratio. While many ranges surround Las Vegas, this research will be conducted for multiple alluvial fans that originate from the Spring Mountain Range west of the Las Vegas Valley. (Las Vegas, 2004).

Drainage basins create a transportation system of sediments that forever change the soil and landscape of the alluvial fans below. Larger drainage basins typically allow for higher amounts of debris that spans out into larger fan areas. In addition, fans will often have coarse debris, which has a large impact on the soil and vegetation, or lack thereof, found in the valley below. The research will focus on several geographical areas, most notably the physical geography of landforms. Geology and climate are vital the structure and size of alluvial fans, impacting erosion and toughness, contributing to the ease with which materials can be transported downward to form the alluvial fan.

Climate, faults, slopes, and geology of an area are some of the primary variables that can have an impact on the size of alluvial fans (Parsons, 2009). With so many variables, recording the basin to fan ratio is an important first step in understanding how geomorphology processes may have impacted the transportation process. Depending on the results, I expect additional research will be conducted that may explain how climate or plate tectonic activity accounts for differences found in the sizes of the Spring Mountain basin to fan ratio.

I am interested in comparing the relationship of alluvial fans and drainage basin area in the Spring Mountains to other desert areas around the world. With my focus strictly on arid climates, it is important to note that these climates have not been consistent throughout history. Las Vegas has perhaps had a higher volume of rainfall or extreme winds that led to faster erosion. Since geomorphology in the study area has happened over millions of years, I intend to account for climate and other historical factors in explaining obscure results in the basin to fan ratio observed. Prior to performing my research, I hypothesize that drainage basins and alluvial fans in the Spring Mountains surrounding Las Vegas have a consistent relationship to those found in other arid climates around the world.

Beginning with a literature review, I will present research that helps explain key concepts on the relationship between drainage basins and alluvial fans. I intend to find research that can account for alluvial fan creation as well as area limitations that can be explained. By comparing other researcher's methods, I hope to understand how Las Vegas alluvial fans can contribute to further research questions. Next, I will present the background for the study site of the Spring Mountains in Las Vegas. I will focus on explaining the variables of climate, geology, faults, and earthquakes. In the methods section that follows, I will provide a guide to replicating my own research using Google Earth Pro and data tables to determine the basin to fan ratio.

After explaining how to replicate the research, I will share my results by accumulating data from all basin to fan ratios studied. I will then explain how these results either accept or refute my hypothesis that drainage basins and alluvial fans at the base of the Spring Mountains have a consistent relationship to other such landforms found in arid climates around the world. Lastly, I intend to share any limitations I encountered while gathering or analyzing research and discuss how my findings compared to the findings of other alluvial fan research in arid climates.

Literature Review

The following section divides three different research areas involving drainage basins and alluvial fans. The first section has prior literature on the variables that affect the geomorphology of alluvial fans. The literature describes the different sediment transportation methods, slope, and climate. Next, the focus will shift to other research methods used to determine the relationship between drainage basins and alluvial fans. In this section, the formula presented will serve as a comparison point between drainage and fan areas in different studies. Lastly, the focus of research is on understanding if the drainage basin and fan relationship differs depending on key factors. Arid fan literature will be discussed to determine how the results obtained for fans in the Spring Mountains will compare to other similar climates.

Prior research results on variables affecting alluvial fan morphology

Alluvial fans form when there is "a sufficient sediment supply, sediment accumulation, and adequate relief for vertical fan growth (Blainey and Pelletier, 2008)." While these elements define the when and how, deeper investigation into variables affecting alluvial fan geomorphology can more clearly explain why alluvial fans change in different environments. Since research into alluvial fans has mostly been conducted within the last several decades, difficulties can emerge in determining why fans in different parts of the world may have a different basin to fan relationship.

According to Griffiths et al., "sediment yield is strongly affected by surficial materials, topography, rainfall seasonality, and vegetation cover (2006)." While topography and vegetation cover can arguably remain consistent, rainfall seasonality is relatively highly fluctuating. Arid fans produce a difficulty since "rates of sediment delivery by fluvial processes in arid landscapes are poorly known, because they are difficult to measure directly (Griffiths et al, 2006)." Even small floods produce an extreme impact on sediment yields and make for larger fan areas. Flood intensity is a key factor in understanding differences between arid area fans around the world and those found in the Spring Mountain Range outside Las Vegas, Nevada.

Additional variables include uplift, depositional processes, and lithology, according to Haug et al. (2010). Considering all variables, basin to fan ratios are expected to see some differences, even in similar arid climates. Determining which areas stand out can narrow down which of the variables mentioned have the largest impact on the relationship between alluvial fans and drainage basins.

According to Ritter et al., climate and tectonics are the two most important variables in determining alluvial fan geomorphology (2000). While both play a major role, some believe that climate is more of a defining point than others. Research by Harvey et al. (2005) supports little difference between fan accumulation in arid environments as opposed to humid environments. Some debate exists, but studies in the southwest suggest one difference is when the debris reaches the fan. In arid environments, sediment is transferred during the warm, dry months, and semi-arid reveals more transfer of deposits during wet, cool months (Ritter et al., 2000). Therefore, fans in arid environments are more prone to sediment deposits caused by slope and gravity. The further the climate gets from arid, the more fluvial processes are involved in fan creation.

The environmental causes for fan creation can be more clearly defined by the slope. Resulting fans reveal which depositional processes created them. Haug et al. state that “steeper fans (~5-15°) are formed by debris flow processes, gentler sloping fan surfaces (~2-6°) are formed by fluvial processes, and the ability of a fan to transport the gravel fraction of sediment diminishes exponentially down profile (2010).”

Prior methods to determine the relationship of Drainage Basins and Alluvial Fans

Equation (1), is a verifiable formula for fans located in the southwestern USA, and has been found “valid, generally, with variations in the values of coefficients c and n reflecting local differences in tectonic activity and the geologic and environmental characteristics of the source basins (Giles, 2010).” Area of the fan and basin are represented by Af and Ad respectively.

$$Af=cAd^{n} \text{ (Giles, 2010)} \qquad (1)$$

As Giles describes, “c is the graph intercept value and n is the proportionality coefficient that represents the slop of a best-fit line and is a positive value, reflecting that larger drainage basins generally produce fans with larger areas (2010).”

Giles argued alluvial fans are three dimensional which makes recording the volume of a fan more accurate than the area in basin to fan ratio research. Typical studies of the past twenty years have relied on area measurements as an accurate way to describe the drainage basin and fan relationship. Giles suggests that the thickness of the fan has been ignored during prior research, and it is hard to argue that fact. However, his findings suggest that fans do not end up becoming small area fans with thick sediment deposits.

The sediment is distributed in such a way that spreads out over an area consistent with the size of the drainage basin; therefore, allowing the two-dimensional basin to fan ratio method to hold up in terms of research functionality. Giles point out that this is especially true for non-subsiding basins (2010). Complex, three dimensional models provide accurate statistics for alluvial fan process such as erosion and accumulation build-up; however, one-dimensional methods are sufficient for results that display major relationships in alluvial fan morphology (Haug et al., 2010).

Close examination of a fan (Figure 1) provides information into how recently sediment may have been transported. Fluvial flows provide evidence that recent activity has taken place, but many arid environments will exhibit inactive alluvial flows (de Haas et al., 2014).

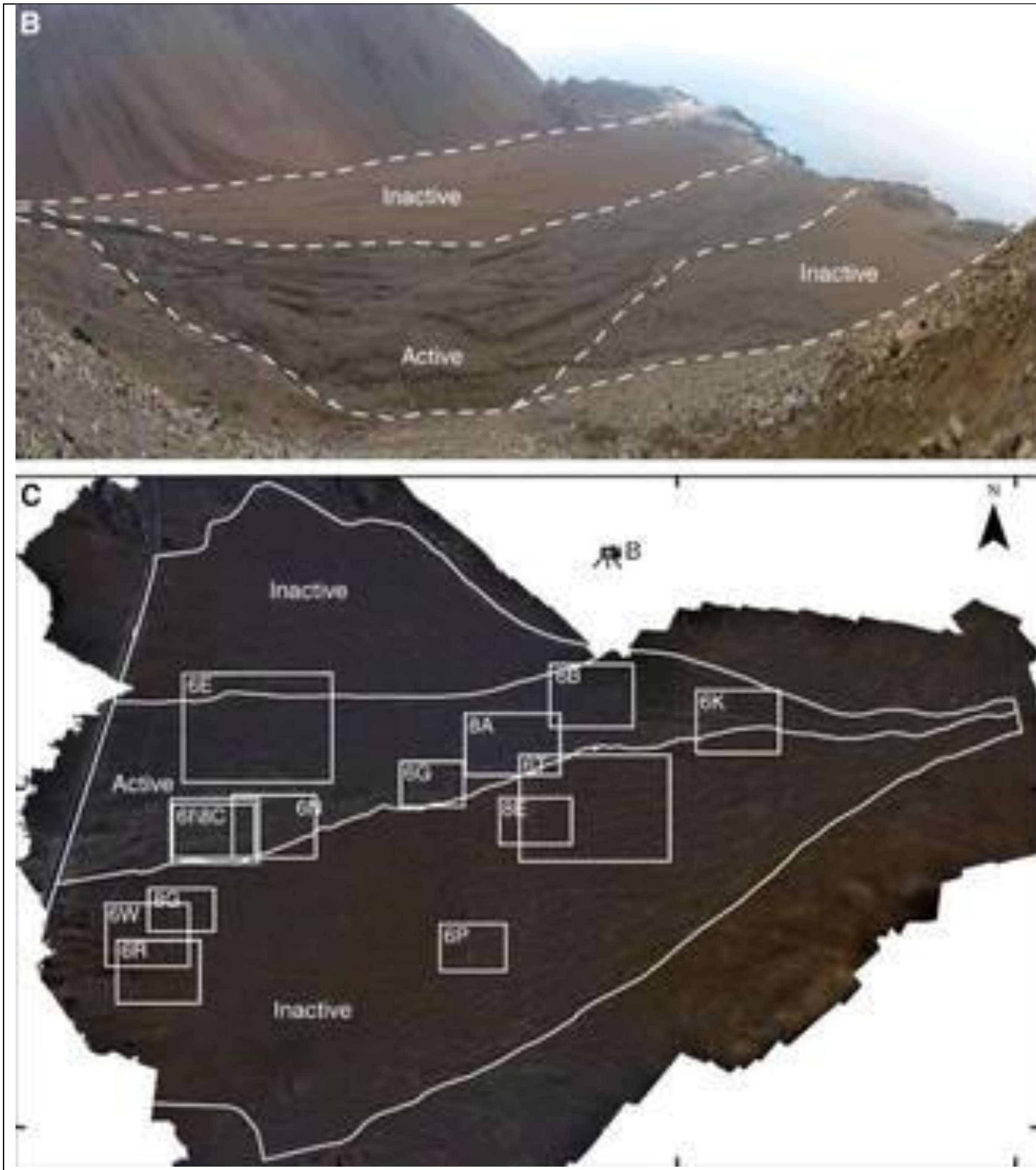


Figure 1. A close-up photo(B) shows parts of alluvial fan that are active and inactive near Atacama Desert, Chile. The overview (C) displays a larger scale look at the active sections of the study. Source: de Haas et al., 2014, pg.167

Prior research results on relationship between alluvial fans and drainage areas in arid climates

Around thirty percent of land in the southwestern U.S. is comprised of alluvial fans (Blainey, 2008). Alluvial fans are abundant and large in the southwest. Alluvial fans in arid areas provide more distinct, clear boundaries than areas with higher vegetation. With study into alluvial fans still relatively new, it comes as no surprise that the most abundant and easiest to see are studied most often.

Basins and fans located in the Atacama Desert in Chile suggest that the shape of a fan is highly changed due to even small rain events (Haug et al., 2010). Strong, small rain events carry enough sediments to perhaps add a significant amount of area to a studied fan. The most arid landscapes experience so little rainfall that a minor change in climate is a large factor in determining the basin to fan relationship.

Another consideration is how weathering creates a boundary that is hard to determine. De Hass et al. points out that over time, arid environments create very small sediments that can fan out into "desert pavement and subdued, incised surfaces (2014)." A lot of these fan are abandoned, and therefore such evidence could reveal that the top of the fan exhibits more recent fluvial flood processes or shapes than does the lower section.

The Sierra Nevada Mountains, the closest of which resting just over 150 miles west of Las Vegas, reveal that fans in arid landscapes present key limitations on studying the basin to fan relationship. Larger basins are limited by channel storage and transmission losses that does not occur when the basins are smaller (Griffiths et al., 2006). While all research points to larger basins producing larger fans, Griffiths study provides a limit on the largest basins. Several large basins will not release all available sediments to the fan below.

Basin to fan ratio is typically depicted as a log log plot with alluvial fan area as the y value and drainage basin area as the x value (Figure 2). The study conducted in North Central Nevada displays a log log plot using an equation (1) with larger drainage basins producing larger fans. The exponential best fit curve is seen trending upwards in both the Hawley and Wilson 1965 study and the Ritter study (Ritter et al., 2000.) The data reveals that Ritter's study had larger fan and basin areas overall, which could contribute to the change in slope and intercept.

The normal value of n (equation 1) is between .7 and 1.1 (Giles, 2010). The n value that represents arid fans and basins has an average of .9, whereas humid fans normally are closer to .6 for n (Giles, 2010). The research shows that Ritter's (Figure 2) findings were unusual, and Hawley and Wilson findings displayed in the table are more representative of alluvial fans in arid climates. According to Giles (2010), the change is c value is much more a product of regional factors such as tectonics or climate.

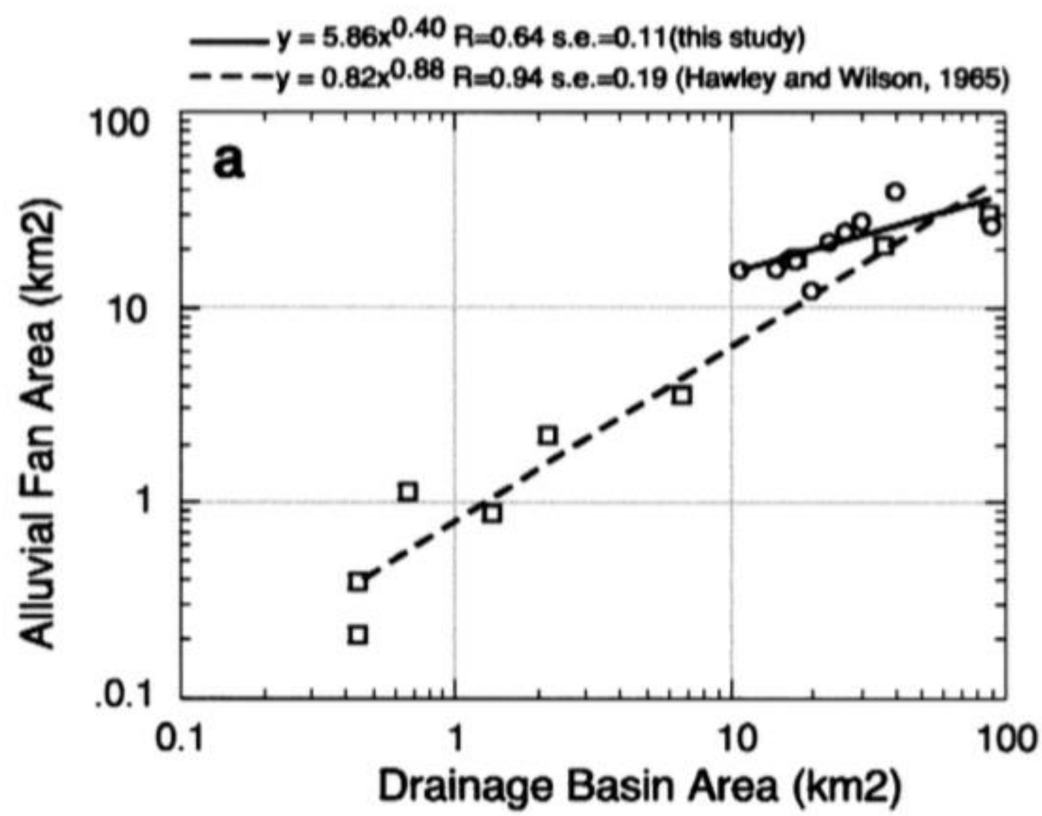


Figure 2. A log log plot displaying drainage basin area as the independent variable and alluvial fan area as the dependent variable. The graph displays two studies in Central Nevada. The dashed line represents a slope of .88 that is more consistent with results found on the relationship in arid environments. Source: Ritter et al. (2000, p. 69)

Study Site

The research will focus on the Spring Mountains that lay just west of the city of Las Vegas in Clark County, Nevada. Located in the southwestern United States, this range makes fans easily visible, which is common for the area. The Spring Mountain range spans an area just around fifty miles. The Spring Mountains stand out due to high peaks and unique areas such as the Red Rock Conservation area.

The Spring Mountains reside in an arid climate which will fit the description of the comparison fans discussed in the literature review. Since measurement tools such as GPS are not being used, it is important that the Spring Mountains have fans that stand out visually. The site was chosen due to large variation in fan area. An overview of the Spring Mountains (Figure 3) shows very large alluvial sediment distributed on the southwest and northern parts of the range.

These large fans are surrounded by many smaller fans surrounding the entire mountain range and stretching into the Las Vegas Valley.

Figure 3.

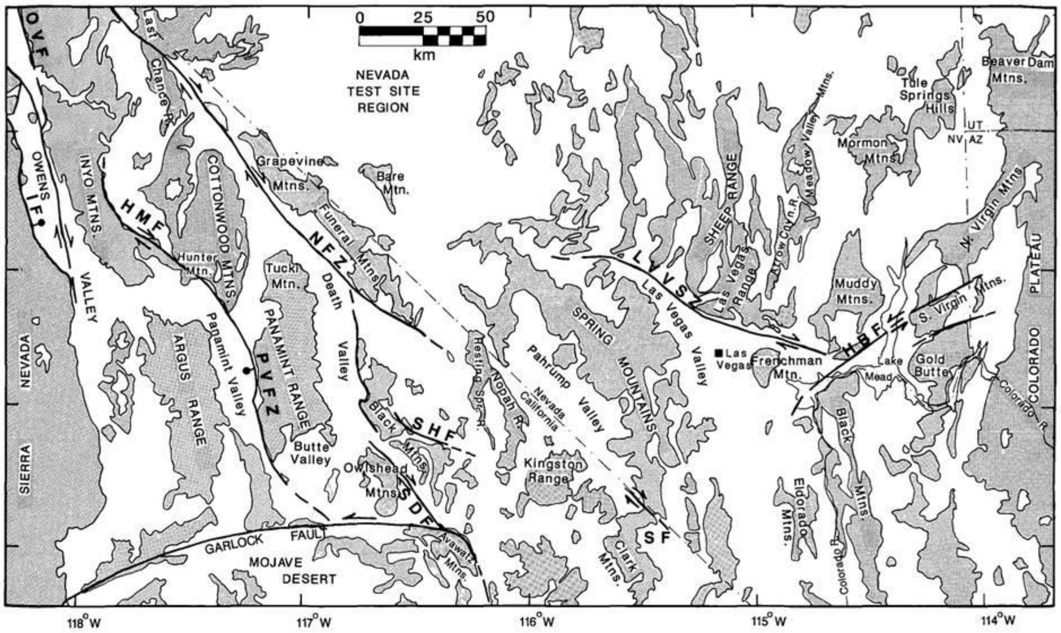
Overview of Spring Mountains (centered, above Las Vegas and Enterprise) as seen from the west.

Imagery used following Google guidelines: https://www.google.com/permissions/geoguidelines.html.

The overview (Figure 3) displays Las Vegas Valley to the east and Pahrump Valley to the west of the mountain range. The research conducted will take a sample of fans from both valleys. Fault lines affecting the Spring Mountain area and Las Vegas and Pahrump valleys are observed surrounding the mountain range (Figure 4). The Las Vegas Valley Shear Zone (LVVSZ in Figure 4) may have created disruption that leads to an abrupt stop to alluvial fans spanning down the northern side of the Spring Mountains. The fans on the northern side of the range also originate from Mount Charleston, which is the largest peak in the range. The extreme slope mixed with the fault line may create a more unique basin to fan relationship.

Climate in the region where the Spring Mountains reside consists of dry, hot summers. Precipitation varies by elevation, where the valley acquires around 200mm and the mountains can receive upwards of 600mm (Winograd et al., 1998). Most of the annual rainfall takes place between Fall and Spring (Winograd et al., 1998). The rain that falls in the hot summer months typically consists of short duration, high intensity precipitation, which has a large impact on the fan's area and shape.

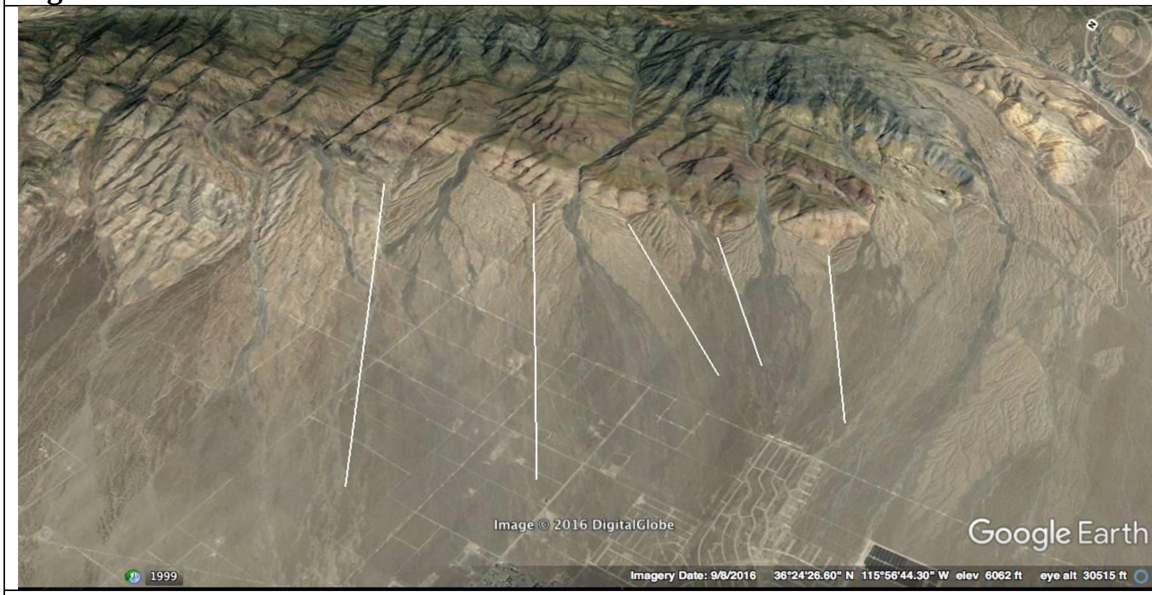
Figure 4



The Spring Mountains in the center of the map can be seen surrounded by the Las Vegas and Pahrump valleys. There are two fault lines are within close proximity to the Spring Mountains. First, notice the the Las Vegas Valley Shear Zone (LVVSZ) located northeast of the mountains. Additionally, the State Fault runs along the border of California and Nevada, spanning from the southeast to northeast of the mountain range. Source: Wernicke et al. (1988, pg. 1742)

Considerations for recording data in this area include many disruptions that do not allow fans to deposit naturally. For example, (Figure 5) shows aerial views of fans on the western side of the Spring Mountain range that merge. Lines have been added where closer examination is required to determine from which basin the flows originated. In addition, layers of alluvial sediment may be lost due to a more recent flow that was deposited on top of existing debris. In the last decade, the Las Vegas valley has expanded in terms of residential and commercial growth. Structures that sit on top of the alluvial sediment and may make it more difficult to determine fan's boundaries (Figure 6).

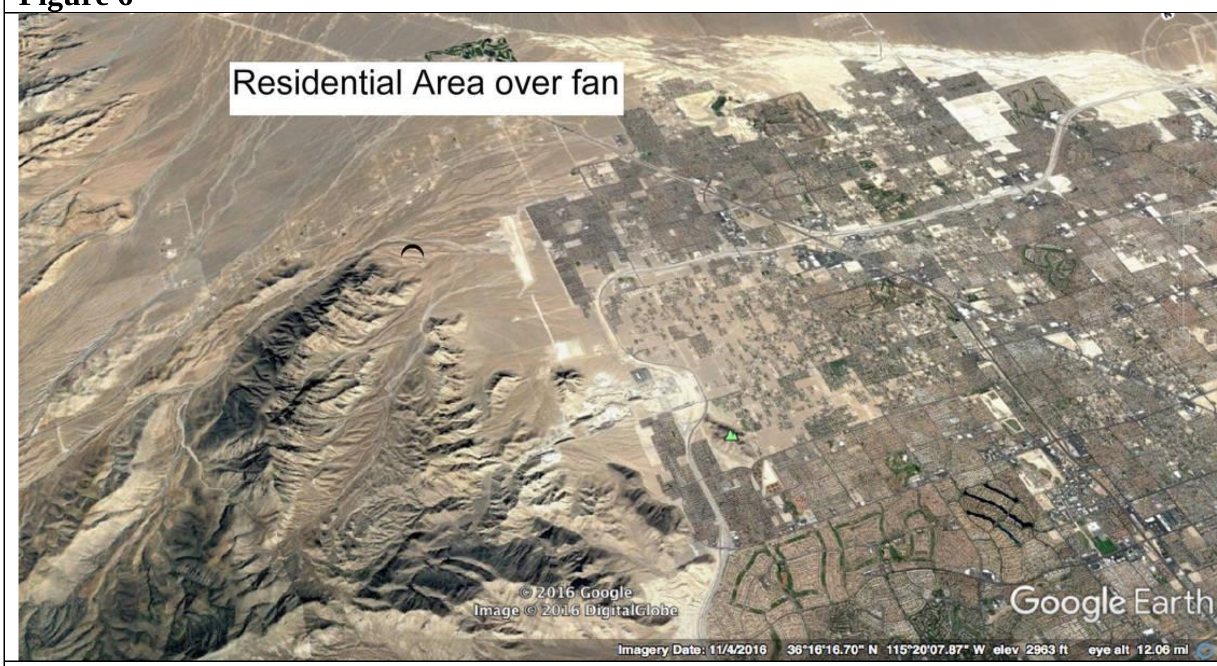
Figure 5



Displayed from the west, alluvial fans merge together but spread long distances down the slope of the Spring Mountain range. Closer examination of the areas displayed with white lines above is required to measure the accurate area for each fan.

Imagery used following Google guidelines: https://www.google.com/permissions/geoguidelines.html.

Figure 6



A fan from the study sample shows a boundary measurement that is obscured by residential and commercial land use.

Imagery used following Google guidelines: https://www.google.com/permissions/geoguidelines.html.

Methods

Set-Up

Explanation

Measuring area of alluvial fans and basins requires Google Earth Pro and Microsoft Excel software installation. Google Earth may be used for data collection, but will require an extra step of obtaining data via a web-based calculation tool. All methods described will assume installation of Google Earth Pro. Before measuring areas, Google Earth Pro must be set up to display aerial imagery as well as topographic data.

Action

1. Install Google Earth Pro and Microsoft Excel.
2. Follow the link https://www.outdoors.org/articles/amc-outdoors/how-to-add-usgs-topographic-maps-to-google-earth/. Instructions are provided for installation to save the file and display as a Google Earth Pro layer. Zoom to area of interest.
3. Open blank worksheet in Microsoft Excel and create a table with headings Fan Area (column B) and Basin Area (column C) in distinct columns. Leave room in column A for labels of specific fans to be measured.

Measurements

Explanation

The measurements needed will consist of a polygon surrounding both the alluvial fan and the drainage area supplying sediment to the fan. Studying the area of interest and becoming familiar is vital to understanding how geomorphology will impact the measurements. Both aerial imagery and topographic information will need to be reviewed to determine the boundaries of the geographic features. The USGS topographic layer that was downloaded will aid in determining the direction of alluvial fans. It will also allow the use of elevation data to better determine drainage basin area for a given alluvial fan.

Action

1. Study area of interest and familiarize the relationship between fans and basins. Look for high peaks and historical or current drainage flows that lead to fans.
2. Turn off the USGS topographic layer in Google Earth Pro.
3. Using the Add Polygon tool in the Google Earth Pro toolbar, begin to measure an alluvial fan by clicking around the entire boundary.
4. Moving slowly, manage fan considerations such as flow direction and merging fans. Once finished, click OK.
5. The polygon should now appear in the Google Earth Pro sidebar on the left. From there, right-clicking and navigating to Get Info allows the option to rename, style, and color the fan area as necessary.
6. Follow the same steps as #2-4 above for the drainage basin.

7. Repeat step #'s 1-6 as needed to measure all alluvial fans and drainage basins in the research area.
8. Turn on USGS topographic layer in Google Earth Pro and double-check the polygons for accuracy.

Calculations

Explanation

Microsoft Excel is the next step in organizing the data obtained from the measurements in Google Earth Pro. The following explains how to retrieve and record the data measured in Google Earth Pro in previous steps..

Action

1. Following step #5 from measurements section, right-click a fan or basin and click Get Info.
2. Navigate to measurements option and observe the measurements of perimeter and area for the chosen polygon.
3. Enter the area value for each fan or basin measured into the Microsoft Excel table from Step #3 in the Set-Up action.
4. Repeat steps #1-3 until columns B and C in the table display all the respective fan and basin area values.
5. Record the Sum and Averages of the data by selecting all the fan area data in the B column and viewing the value at the bottom bar of the Microsoft excel window.
6. Record averages for fan area and basin area below the table in the Microsoft Excel worksheet.

Plotting Graph

Explanation

In order to gather the data, a table and graph needs to be made in Microsoft Excel. The table will display fan and basin area. The graph will have the proper format to compare with other graphs using Formula 1.

Action

1. Make a table with the studied fans on in Column A labeled by number.
2. Make two rows titled Area of Fan and Area of Basin where the titles are in row 1 and the data starts in row 2.
3. Enter each corresponding area measurement to the fans and basins in the table until all rows are complete.
4. Insert a scatter plot graph by selecting it from the toolbar menu.
5. Select Area of Basin for the x-axis and Area of the Fan for the y-axis.
6. Format both x and y axis by right clicking and selecting a logarithmic scale.
7. Format both x and y axis by adding minor gridlines.

8. Right click on one of the data points to add a trendline. Choose format trendline and select the power trendline and check the box to display equation on chart.
9. Label x and y axis and add title. Move the equation to an area where it is easily visible. The final graph should look similar to Figure 7.

Results

In the following, measurement results of alluvial fans and drainage basins from the Spring Mountain Range are presented. Ten total fans were chosen as a sample, representing large, medium, and small fans from the study site. Area was measured for ten alluvial fans and their corresponding drainage basins (Table 1).

Table 1 : Area data for sample of alluvial fans and drainage basins in Spring Mountains

Fan Measured	Area Of Fan(Af) (km2)	Area of Basin (Ab) (km2)	Ab/Af
Fan 1	37.2	123	3.31
Fan 2	21.7	37.9	1.75
Fan 3	11.3	69.6	6.16
Fan 4	50	62.9	1.26
Fan 5	4.32	5.16	1.19
Fan 6	3.25	5.1	1.57
Fan 7	10	12.9	1.29
Fan 8	8.98	9.78	1.09
Fan 9	6.49	6.99	1.08
Fan 10	106	108	1.02
Mean (Fans 1-10)	25.92	44.13	1.70

Fans and basins numbered 1-4 (Table 1) were measured from the eastern side of the mountain range. These fans account for large and medium fans in the sample. Fan 2 was unique because a section of the basin is measured as it runs alongside the fan. This created a thinner fan that runs a longer length than most fans studied. Fan 3 (Figure 3F) accounts for the largest difference in area between fan and drainage basin. The basin that channels debris flow to Fan 3 is 6.16 times larger than the fan. Fan 3 also displays the point furthest from the trend line (Figure 7). Area measurements for Fan 1 (Figure 1F) show a difference in the two recorded areas where the basin in 3.31 times larger than the fan. Fan 1 was the only fan measured that has housing or commercial development built on top of the debris flow.

Fan 10 (Figure 10F), the largest from the study, is located on the southwest side of the mountain range. The drainage basin area spans between Mount Charleston and Griffith Peak, the two largest peaks in the range. The largest drainage basin is the basin that corresponds with Fan 1. This basin is situated between La Madre, Wilson, and Harris mountains. Overall, the average area of the ten fans measured calculates to 25.92 km2. The average calculation for basin area equals 44.13 km2. On average, a basin from this study site will have an area that is 1.7 times larger than the fan below it (Table 1).

Fans 5-9 are the smallest of the study and are situated on the northwestern downslope of the Spring Mountain Range. These fans all have a basin fan ratio between 1.00 and 1.57 (Table 1). These fan areas also fall closer to the trend line displayed on the log log plot (Figure 7) than the larger area fans located on the eastern downslopes.

Figure 1F: Fan 1
Coordinates Fan 1 (Yellow): 36°18'59.00"N 115°19'30.00"W
Coordinates Basin 1 (Blue): 36°14'12.00"N 115°30'16.00"W

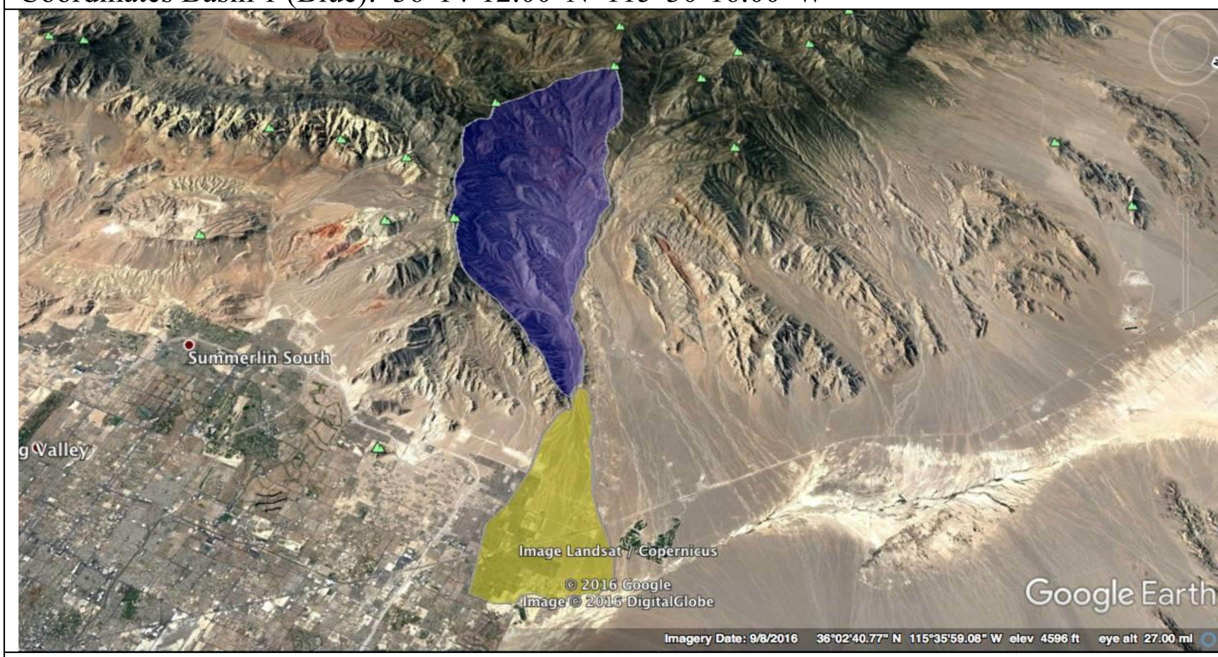


Figure 1: Fan 1 Imagery used follows Google guidelines: https://www.google.com/permissions/geoguidelines.html.

Figure 2F: Fan 2
Coordinates Fan 2 (Yellow): 36°23'08.00"N 115°29'05.00"W
Coordinates Basin 2 (Blue): 36°20'47.00"N 115°32'09.00"W

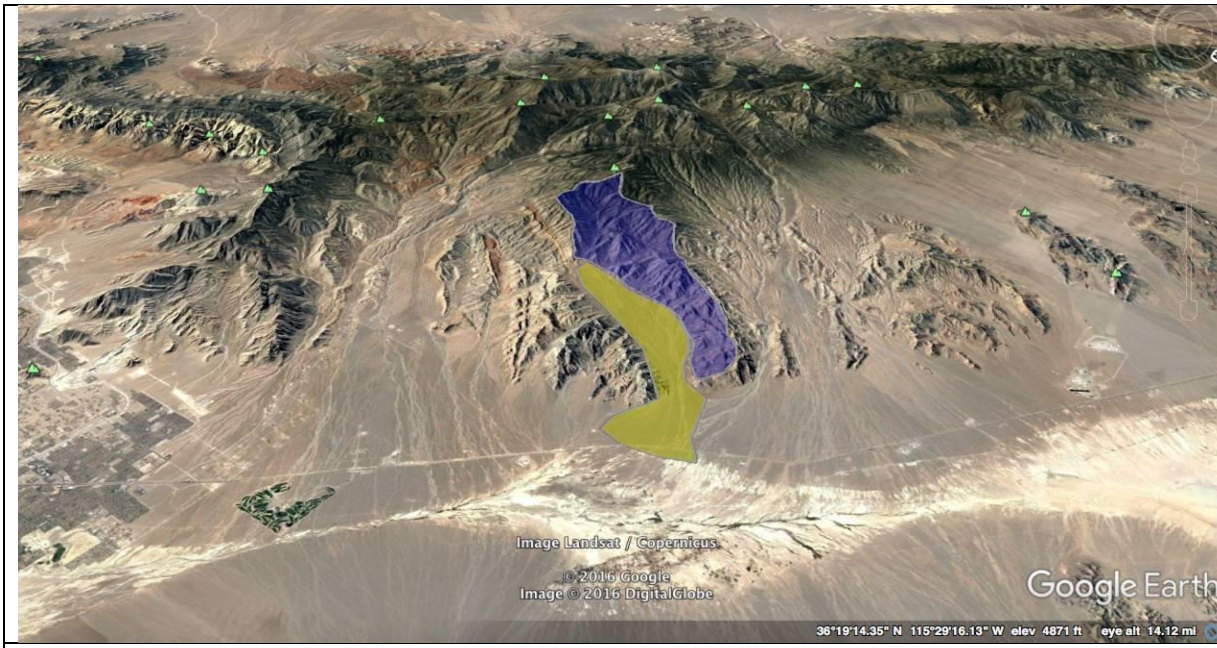


Figure 2: Fan 2 Imagery used follows Google guidelines: https://www.google.com/permissions/geoguidelines.html.

Figure 3F: Fan 3
Coordinates Fan 3 (Yellow): 36°26’29.00”N 115°27’09.00”W
Coordinates Basin 3 (Blue): 36°21’29.00”N 115°35’12.00”W

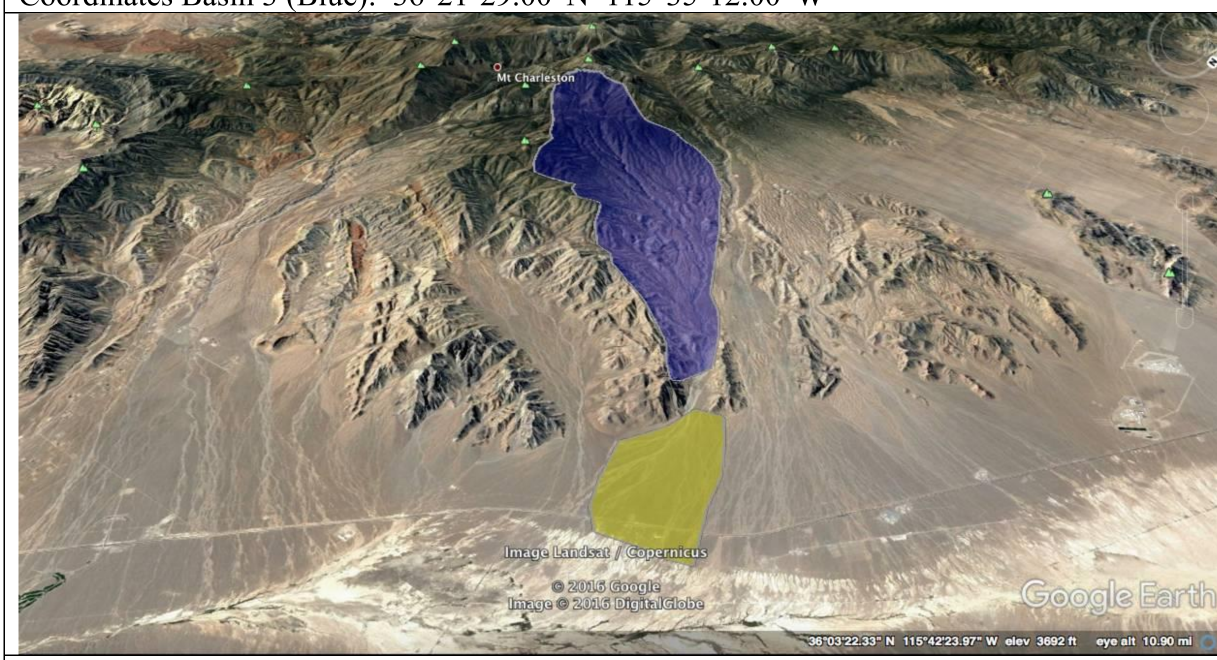


Figure 3: Fan 3 Imagery used follows Google guidelines: https://www.google.com/permissions/geoguidelines.html.

Figure 4F: Fan 4
Coordinates Fan 4 (Yellow): 36°28’27.00”N 115°29’32.00”W
Coordinates Basin 4 (Blue): 36°19’16.00”N 115°40’05.00”W

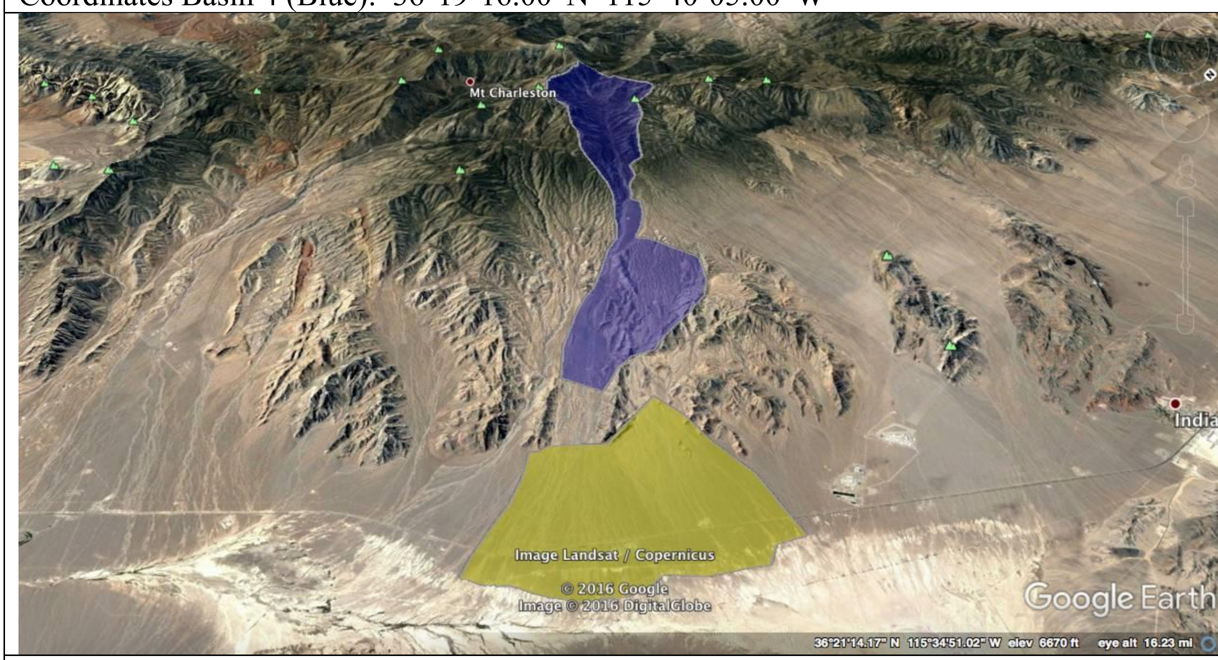


Figure 4: Fan 4 Imagery used follows Google guidelines: https://www.google.com/permissions/geoguidelines.html.

Figure 5F: Fan 5
Coordinates Fan 5 (Yellow): 36°18’16.00”N 115°55’34.00”W
Coordinates Basin 5 (Blue): 36°19’26.00”N 115°53’05.00”W

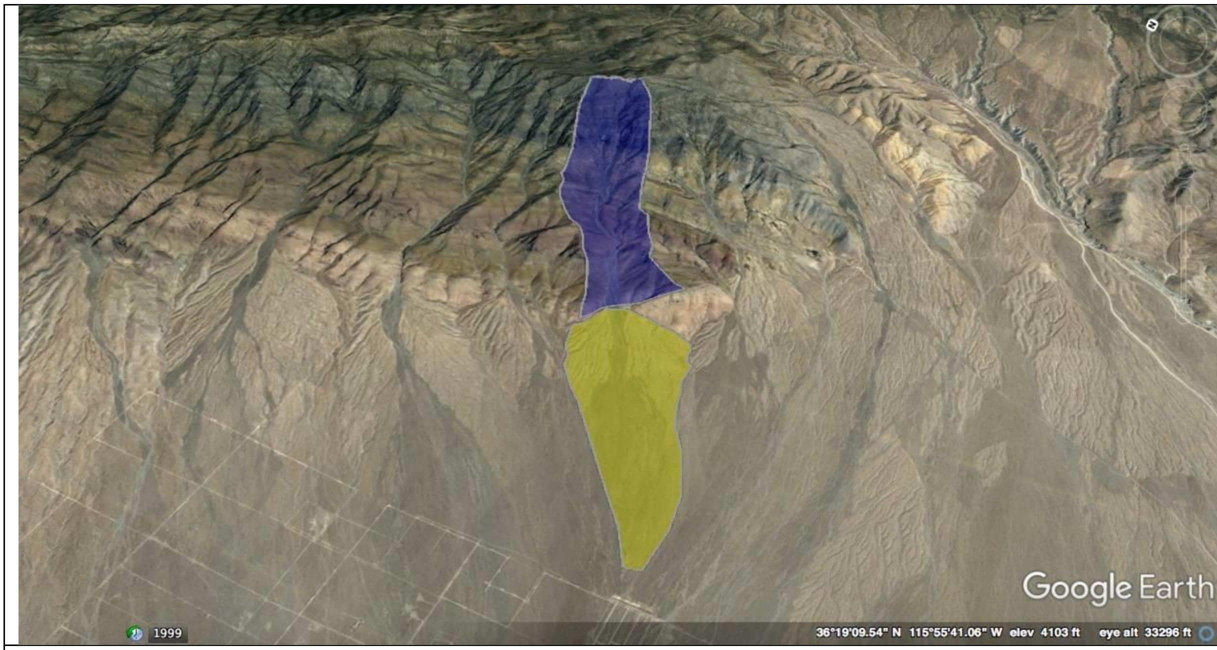


Figure 5: Fan 5 Imagery used follows Google guidelines: https://www.google.com/permissions/geoguidelines.html.

Figure 6F: Fan 6
Coordinates Fan 6 (Yellow): 36°19'01.00"N 115°55'48.00"W
Coordinates Basin 6 (Blue): 36°19'51.00"N 115°54'05.00"W

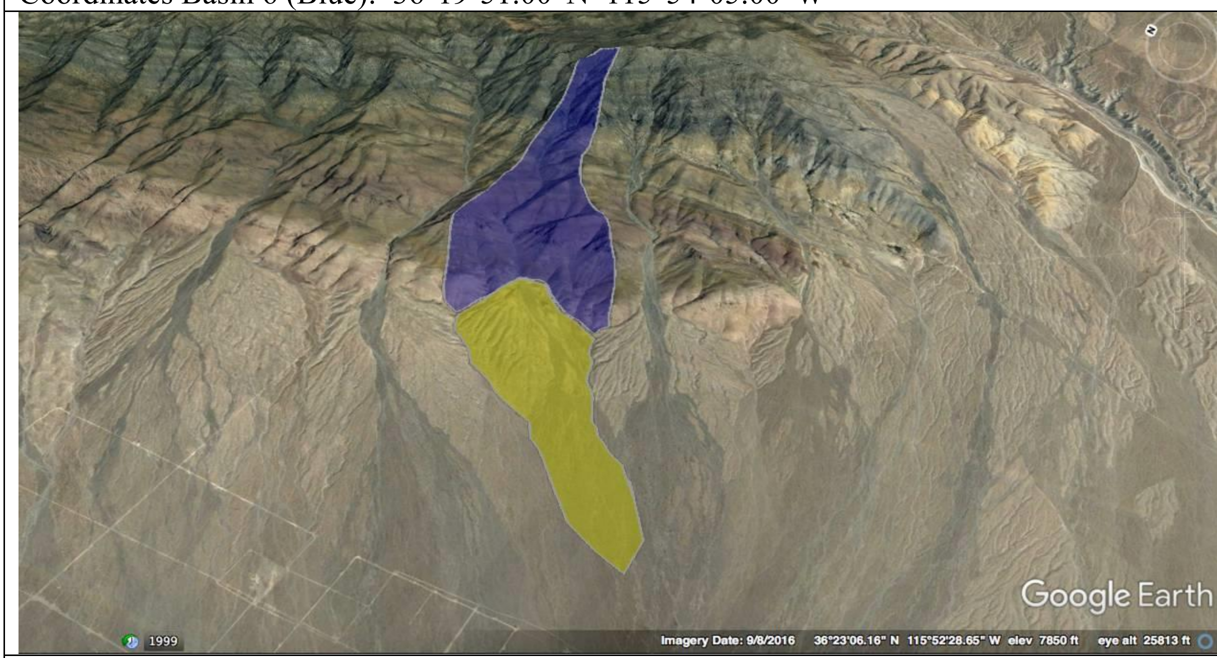


Figure 6: Fan 6 Imagery used follows Google guidelines: https://www.google.com/permissions/geoguidelines.html.

Figure 7F: Fan 7 Coordinates Fan 7 (Yellow): 36°19’01.00”N 115°57’08.00”W Coordinates Basin 7 (Blue): 36°20’57.00”N 115°53’16.00”W

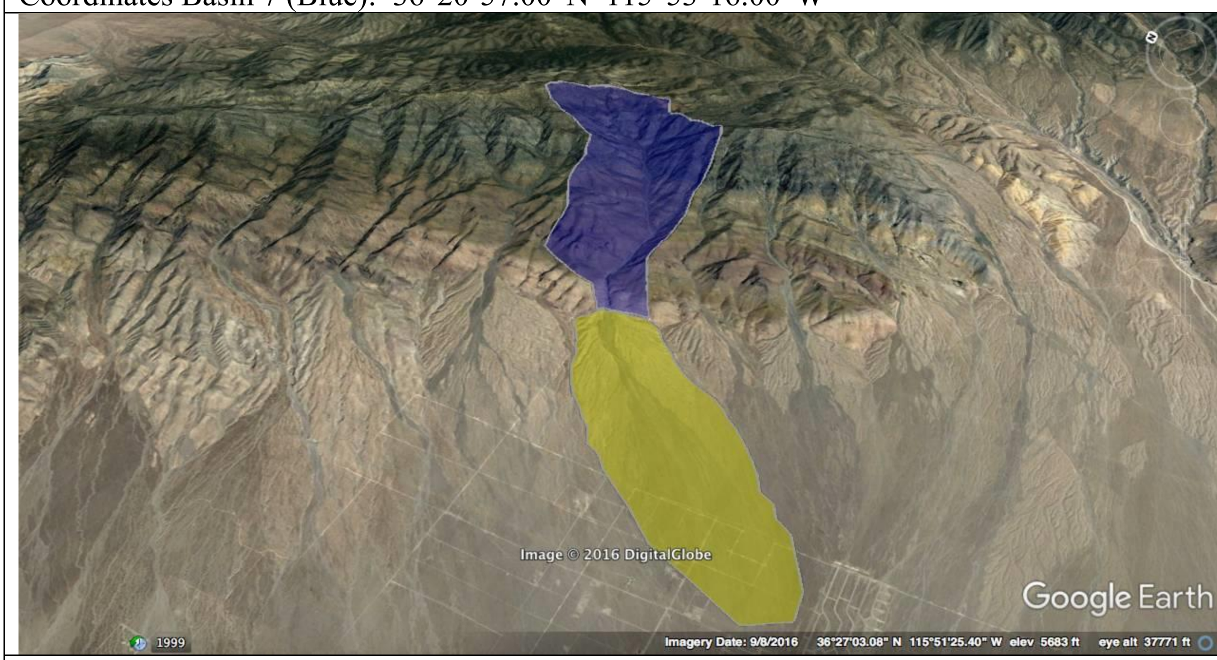


Figure 7: Fan 7 Imagery used follows Google guidelines: https://www.google.com/permissions/geoguidelines.html.

Figure 8F: Fan 8 Coordinates Fan 8 (Yellow): 36°20’39.00”N 115°57’08.00”W Coordinates Basin 8 (Blue): 36°21’56.00”N 115°53’45.00”W

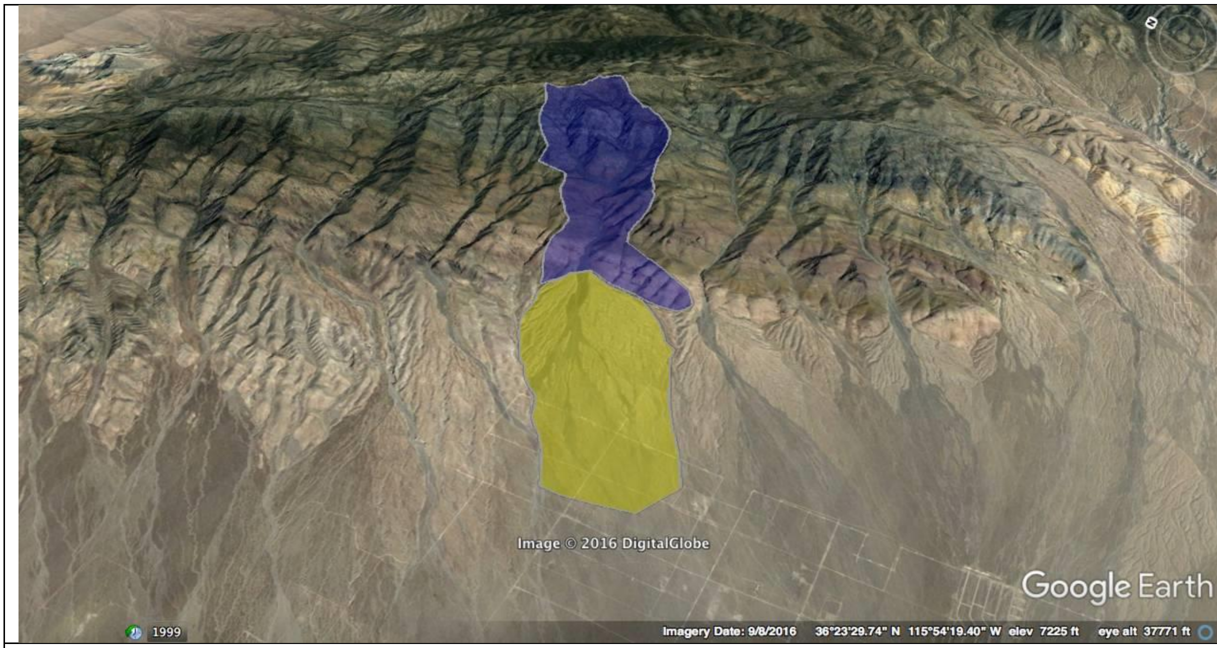


Figure 8: Fan 8 Imagery used follows Google guidelines:
https://www.google.com/permissions/geoguidelines.html.

Figure 9F: Fan 9
Coordinates Fan 9 (Yellow): 36°17’29.00”N 115°54’51.00”W
Coordinates Basin 9 (Blue): 36°18’31.00”N 115°53’03.00”W

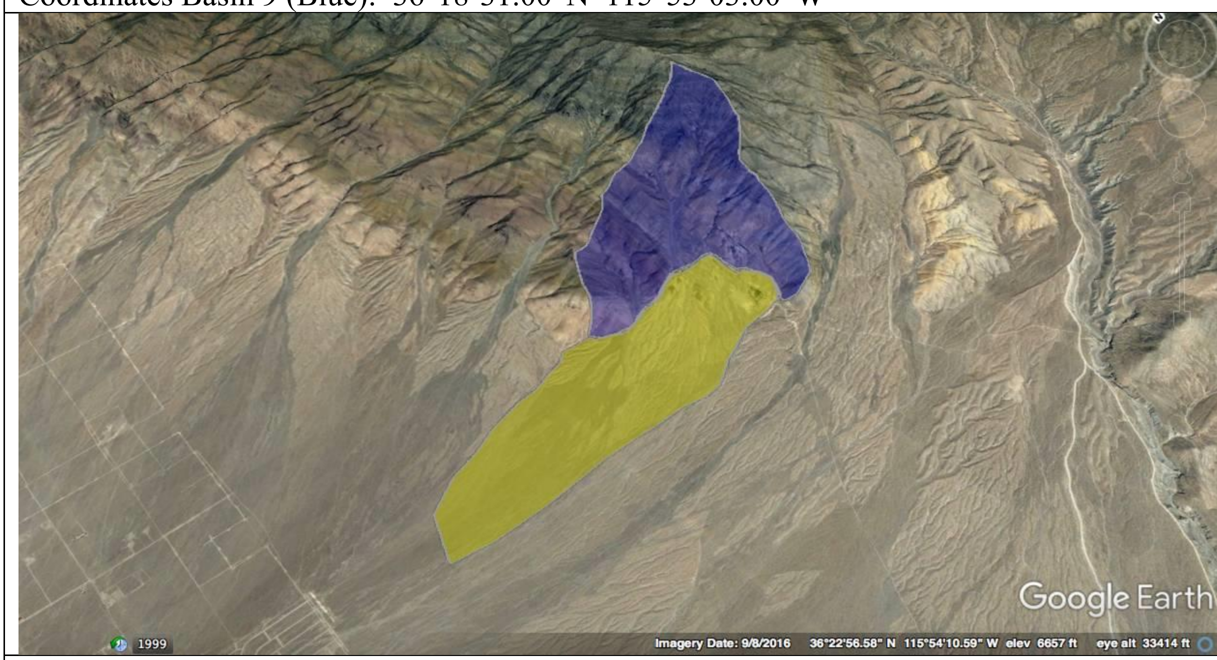


Figure 9: Fan 9 Imagery used follows Google guidelines:
https://www.google.com/permissions/geoguidelines.html.

Figure 10F: Fan 10
Coordinates Fan 10 (Yellow): 36°05’03.00”N 115°48’28.00”W
Coordinates Basin 10 (Blue): 36°10’59.00”N 115°41’06.00”W

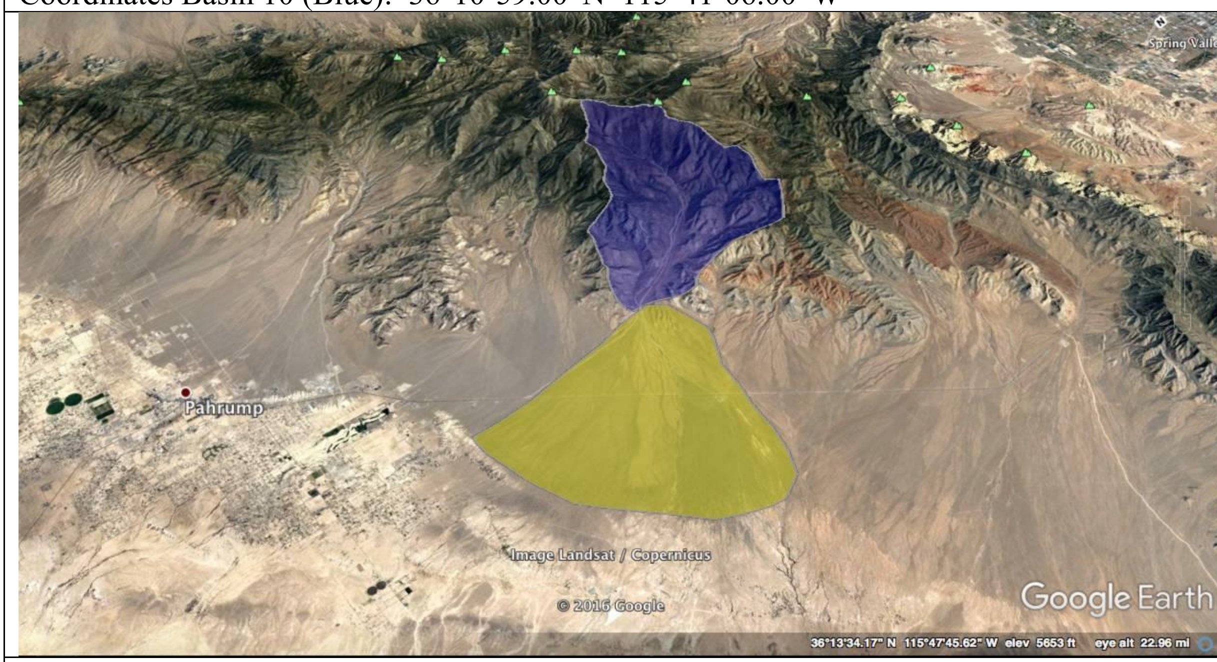
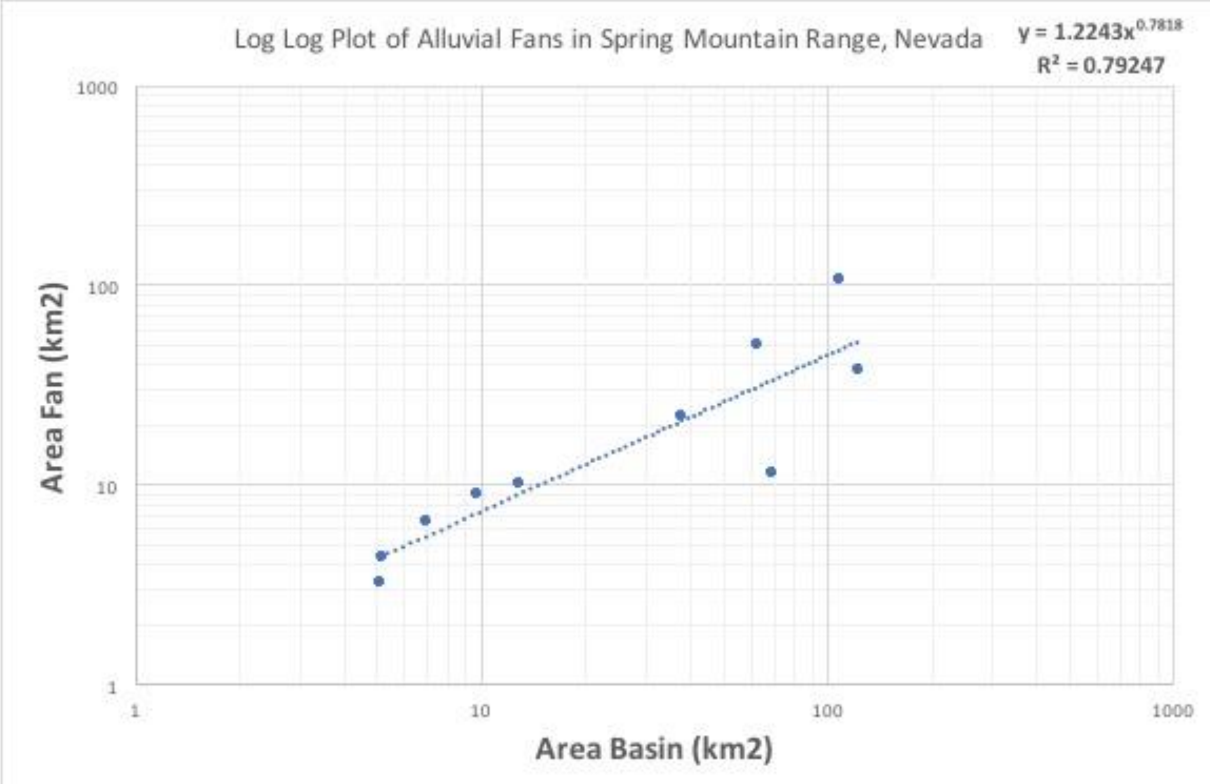


Figure 10: Fan 10 Imagery used follows Google guidelines: https://www.google.com/permissions/geoguidelines.html.

The graph displays data collected from ten alluvial fans and drainage basins. The y-intercept is equal to 1.22. The graph displays drainage basin area as the independent variable, and alluvial fan area as the dependent variable. The slope of the line goes upwards from left to right and the slope is .7818 (Figure 7).

Figure 7: Graph displaying fan and basin area relationship with trend line from the data of ten alluvial fans resulting from basins in the Spring Mountain Range, Nevada.



Discussion

Re-examining the Hypothesis

Answering whether Spring Mountain fans differ from those in arid areas requires examination of the outlying data. The range includes large fans and basins (Figures 1F and 10F) that can be connected to the largest peaks. Incorporating the large fans and basins is vital to fully understanding the Spring Mountains. Medium and small fans studied were more similar to each other and with more measurements would eventually overrule the outlying larger fans in terms of data recording. Even with a few fans that exhibit an unusual relationship, the results prove that the relationship between drainage basins and alluvial fans in the Spring Mountain Range are consistent with those found in other arid climates.

The results compare two different areas that represent a starting point, the basin, and the resulting alluvial fan. Clearly, larger basins result in larger fans. Some outlying results were discovered. For instance, the largest basin measured (Figure 1F) did not have the largest fan. The basin area was over three times larger than the area of the corresponding alluvial fan. An even stronger distinction was made for Fan 3 (Figure 3F). The basin area was over six times larger than the fan area. Aside from these two, all other eight fans had a consistent basin to fan ratio (Ab/Af) of between 1 and 1.75. It's expected that measuring all the fans of the Spring Mountains would narrow this number even further, approaching 1.1. The ratio would fall because the amount of small to medium fans is much greater than the number of large fans across the range. The Spring Mountains of Las Vegas have unique properties that transformed the landforms of alluvial fans, but the relationship between alluvial fans and drainage basins is consistent with other relationships studied in arid climates. The most notable result is the n coefficient for slope of .78, which will be compared to prior research for validation in the connections to prior scholarship section below.

Limitations

Three main limitations are noted for the research results recorded during the study. First, it is unknown whether alluvial fans are active. The data collection consisted of aerial imagery, which don't often give the fidelity necessary for understanding the recent debris flow activity from a basin (Figure 1). If active, drainage basins may still be supplying the fan and increasing the fan's area. The longer a fan is inactive, the more weathering and erosion will affect the shape and size of the fan. Gaining closer access and more time for study would allow greater comparison of the drainage basin and alluvial fan relationship than conducting a study with primarily satellite imagery.

Another limitation for the study was the method of measurement. Google Earth Pro is used for data collection, but is not as accurate as GPS technology (Figure 8). The GPS data also includes elevation to aid in the boundary recognition, but require more resources than were available for use during this study. Further studies of the Spring Mountain range could include GPS data for more precise calculations. The manual method used for determining area consists of the user determining the boundaries and marking using Google Earth Pro tools. The inconsistency in measuring each boundary is certainly a factor in interpreting the results of drainage basin and area.

Lastly, fans that compete for space will affect the boundaries and area that is recorded for the dataset. Many fans, especially those on the west side of the Spring Mountains (Figure 5), compete with each for lateral space. More active flows could cover inactive fans and skew the area results that are obtained from the study. Careful consideration was placed on flows, and only those flows that appeared as a direct result of the basin were considered as a part of the area for that fan. Several hours were spent more clearly defining the separation as can be viewed by comparing Figure 5 to Figure 5F or 7F, but ultimately the study cannot fully account for this variable.

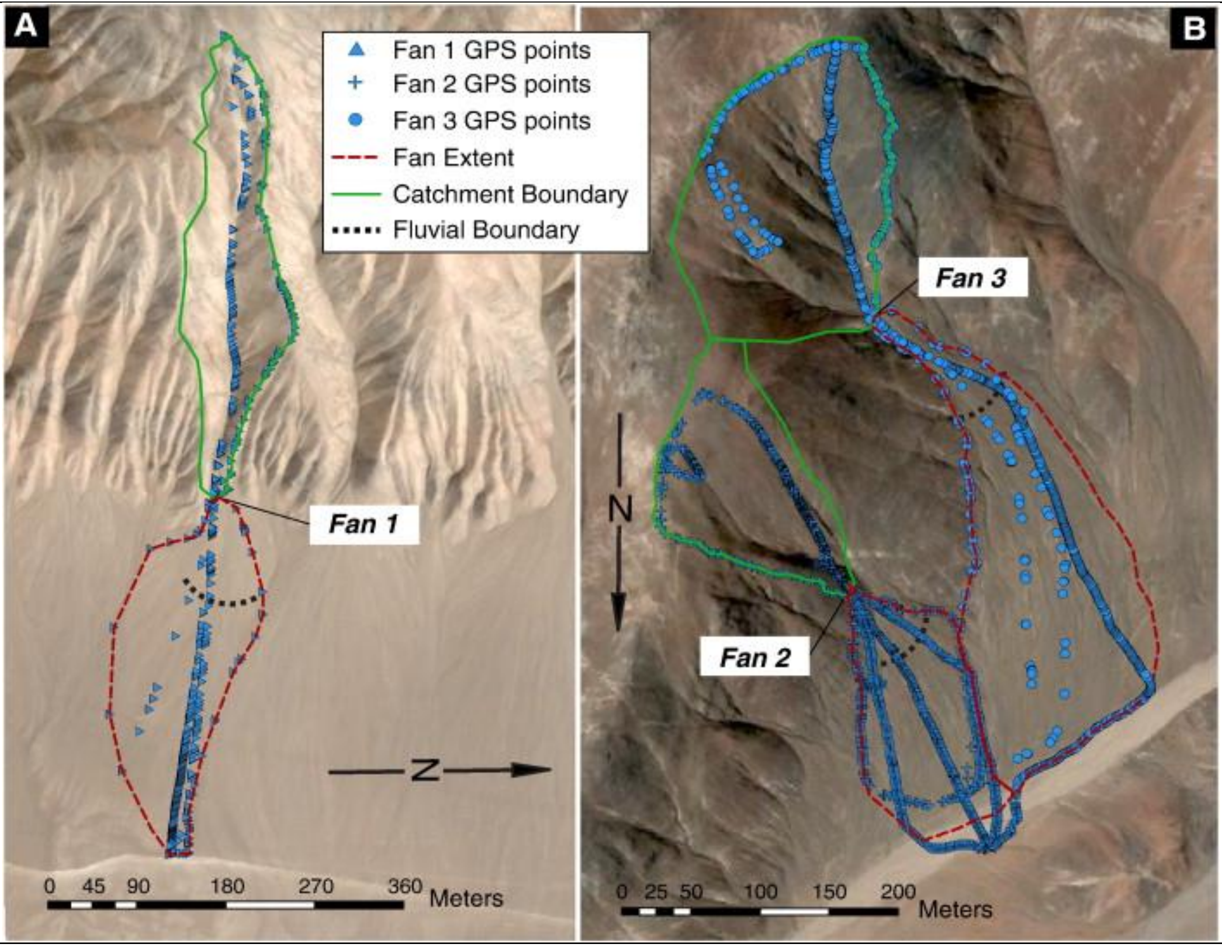


Figure 8. GPS data for measuring fans and basins provide higher accuracy than the methods described in this study, but require .
Source: Haug et al. 2010, pg 187

Connections to Prior Scholarship

Using the equation for basin and fan relationship (Formula 1), the results show (Formula 2) that the drainage basin and fan relationship in the Spring Mountain Range has an intercept value of 1.22 and slope of .7818.

$$y=1.2243x^{.7818} \qquad (2)$$

The coefficient (n) for the power slop of the trend line is the best tool in the formula for comparing basin to fan ratio data. The value obtained is within the normal value of n range, which is between .7 and 1.1. Arid fans have a value of n near .9, and humid fans are normally closer to .6 (Giles, 2010). The obtained value of n=.7818 falls into an expected range for fans in this environment. It also measures closer to .9 than to .6, which suggests that the hypothesis is accepted.

Two fans differed significantly from the other eight in that the large area basin did not provide as large of an area fan as expected. Figure(s) 1F, 3F provide the examples of this claim. Griffths et al. study in the Sierra Nevada mountains concluded that limitations are placed on larger basins (2006). Additionally, limitations are visible at the bottom of both fans, resulting in an area measurement that may be cut short. The data (Table 1) shows the high difference in the relationship between these large basins. While there was a large basin for Fan 10 (Figure 10F), it is worth noting that the fan area was more consistent with the expected results according to the graphs (Figure 7) trend line. Nevertheless, Fans 1 and 3 provide data that suggest Griffiths was right about some large fans not releasing all available sediments.

In addition to the basin limitations, de Haas et al. points out that arid landscape fans spread out in a "desert pavement" (2014). Weathering alters the fan into very fine sediment that may not have been recorded in area calculation method used in this study. Combined with fans that stretch into residential areas (Figure 1F) and a limiting rock structure (Figure 3F), visual identification of boundaries could produce a fan that was recorded smaller than it's true size.

Conclusion

The purpose of this research was to determine whether the Spring Mountains in Las Vegas, Nevada had a basin to fan relationship that was consistent with other arid climates. The research was based on calculations of fans and basins areas, and the resulting graph (Figure 7) displays a trend found in research of other arid climates. Research was conducted in the Spring Mountains using Google Earth Pro software and comparing the areas to create the graph and table (Figure 7, Table 1). The data was then compared to prior research using an accepted formula (Formula 1). The sample of fans taken from the Spring Mountains was diverse, exhibiting differing characteristics such as size and debris accumulation methods. This allowed characteristics to be examined and elicit further research questions explained in this section.

The findings (Table 1) were consistent with the widely-accepted theory that larger basins produce larger fans. Only two drainage basins (Figure 1F and Figure 3F) had much smaller fans than were expected. Limitations of the study included the lack of GPS technology for precise measurements, the inability to recognize active versus inactive fans, and fans that competed for space and shared boundaries. The ten fan to basin relationships display a trend line that is equal to .7818, which falls inside the range of arid fan trend lines. Prior research places arid fans at a slope around .9 compared to humid fans which are closer to .6 (Giles, 2010). Prior research by Griffiths et al. provides evidence that larger basins have limitations on released sediment to the fan below, which explains why the two larger basins (Figures 1F, 3F) found in this study have smaller fans (2010).

Three questions emerged from the study for future research consideration.

- Do larger basins have limitations on sediment flow?
- Should researchers consider how active the fans are?
- Should there be separation between steeper sloped fans compared to more gradually sloping fans?

First, this study may have aided Griffeths et al. claim about large basins having limited debris flow to fans. Larger basins are limited in storage of debris, and studies may need to account for these limitations. Second, active fans are still in a period of growth. All fans could be active when a large rainfall occurs, so another key question arises in an area to consider the climate. Studies such as this focused primarily on arid locations, and even a stricter climate separation could be beneficial in future studies. Lastly, the slope of the fan should be considered for all studies. This question relates to large basin limitation question, but strictly focuses on slope. The main consideration is with regards to transportation of sediments. Higher sloped fans typically have more gravity based rockfall debris than the fluvially transported debris found in gradual fan slopes (Haug et al., 2010). Separating the fans by this distinction could prove valuable in obtain more precise measurements.

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