

JJ Munoz

Helper

GEO 386G

1 December, 2016

GIS Project: Using ArcHydro and Surface Roughness tools to Determine Alluvial Fan Catchment Area Morphology Statistics from 1-meter resolution LiDAR DEM's.

Explanation of the Project/Outline

For this project, we are going to compare the morphologies of two offset Holocene alluvial fans along two distinct strands of the southern San Andreas fault. The ultimate reason for doing this is to see if catchment area morphologies have an effect on the variability of the cosmogenic ^{10}Be surface exposure ages that were measured by two separate studies (Gold et al., 2015; Munoz et al., 2016 (in progress)). When measuring ^{10}Be concentrations on surface boulders and cobbles, the majority of the variability comes from the inherited component of ^{10}Be , that is to say, ^{10}Be that was acquired by the samples before their deposition on the modern fan. This bodes problematic for the acquired dataset, as the reported ages will be overestimations of the depositional age of the fan. Inheritance can be modeled using certain methods, but sometimes these methods can be rendered useless because the inheritance in the dataset is so high. Therefore, we will explore what influence the catchment area of the alluvial fan might have on the variability of the ^{10}Be dataset. In summary, this project aims to answer the question: *Does alluvial fan catchment area morphology have an impact on the variability of cosmogenic surface exposure ^{10}Be ages?*

A starting hypothesis might be that age variability will increase with however large the catchment might be, because the sediments might have been transported over a longer time/distance, thus acquiring more ^{10}Be . The same could be said for surface roughness, as a rougher surface of the catchment area might lend itself to more mixing upon excavation.

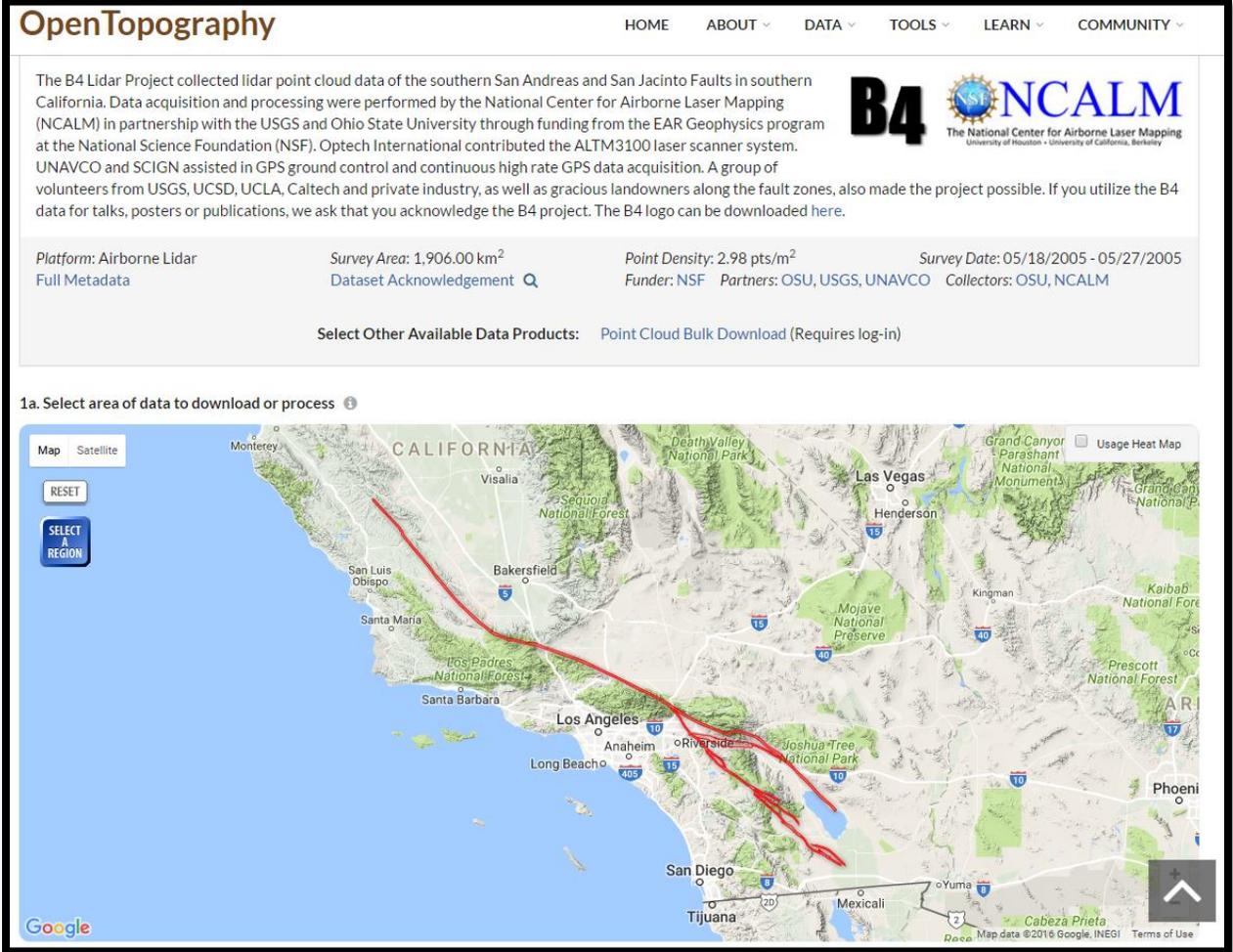
In this project we will:

- 1.1)** Download B4 LiDAR data from OpenTopography, which contains free georeferenced 1-meter resolution airborne LiDAR data.
- 1.2)** Isolate the desired alluvial fan/ basin using the ArcHydro tool box
- 1.3)** Measure the surface area, length, and aspect ratio of the catchment areas.
- 1.4)** Use surface roughness tools determine the surface roughness of the catchment areas.
- 1.5)** Compare these statistics to the variability of the fan ages with respect to the minimum ^{10}Be age. Quantify results and show final maps.

1.1 Data Collection and Preprocessing

The reason these two fans were chosen for comparison were because of the fact that there is high resolution (1 m) airborne LiDAR DEMs available from the B4 project, which is a compilation of point cloud data of the southern San Andreas and San Jacinto faults in Southern California. High-resolution data is very important for this project, as a low-resolution DEM dataset (even as “low” as ASTER’s 30 m stuff) would provide very inaccurate results. To acquire these data, complete the following steps:

- 1.) Go to <http://opentopo.sdsc.edu/lidar> and scroll down to entry #205, which contains the LiDAR acquired from the B4 project. This project was performed by the National Center for Airborne Laser Mapping (NCALM) in partnership with the USGS and the Ohio State University in 2005. Click on this entry.



The screenshot shows the OpenTopography website interface. At the top, there is a navigation menu with links for HOME, ABOUT, DATA, TOOLS, LEARN, and COMMUNITY. Below the navigation is a header section for the B4 project, featuring the B4 logo and the NCALM logo (The National Center for Airborne Laser Mapping, University of Houston - University of California, Berkeley). The main content area contains a detailed description of the B4 Lidar Project, stating that it collected lidar point cloud data of the southern San Andreas and San Jacinto Faults in southern California. It mentions that data acquisition and processing were performed by the National Center for Airborne Laser Mapping (NCALM) in partnership with the USGS and Ohio State University through funding from the EAR Geophysics program at the National Science Foundation (NSF). Optech International contributed the ALTM3100 laser scanner system. UNAVCO and SCIGN assisted in GPS ground control and continuous high rate GPS data acquisition. A group of volunteers from USGS, UCSD, UCLA, Caltech and private industry, as well as gracious landowners along the fault zones, also made the project possible. It notes that if the B4 data is used for talks, posters or publications, users should acknowledge the B4 project and that the B4 logo can be downloaded here.

Below the description is a table of project metadata:

Platform: Airborne Lidar Full Metadata	Survey Area: 1,906.00 km ² Dataset Acknowledgement Q	Point Density: 2.98 pts/m ² Funder: NSF Partners: OSU, USGS, UNAVCO	Survey Date: 05/18/2005 - 05/27/2005 Collectors: OSU, NCALM
---	--	---	--

Below the table, there is a section for "Select Other Available Data Products:" with a link for "Point Cloud Bulk Download (Requires log-in)".

At the bottom of the screenshot, there is a section titled "1a. Select area of data to download or process" with a sub-label "1". Below this is an interactive map of California and the southwestern United States. The map shows major cities, highways, and national parks. A red line is drawn across the map, indicating the selection area for data download. The map includes a "Map" button, a "Satellite" button, a "RESET" button, and a "SELECT A REGION" button. The Google logo is visible in the bottom left corner of the map area.

- 2.) Scroll down past the interactive map and check the box for data selection coordinates, input the following coordinates in the interface. This lab will only provide examples for the Three Palms fan, but make sure you repeat the process for the Painted Hill fan as you go. It might help to complete all of the processing steps for one fan first, and then go back to the beginning.

Three Palms Fan:

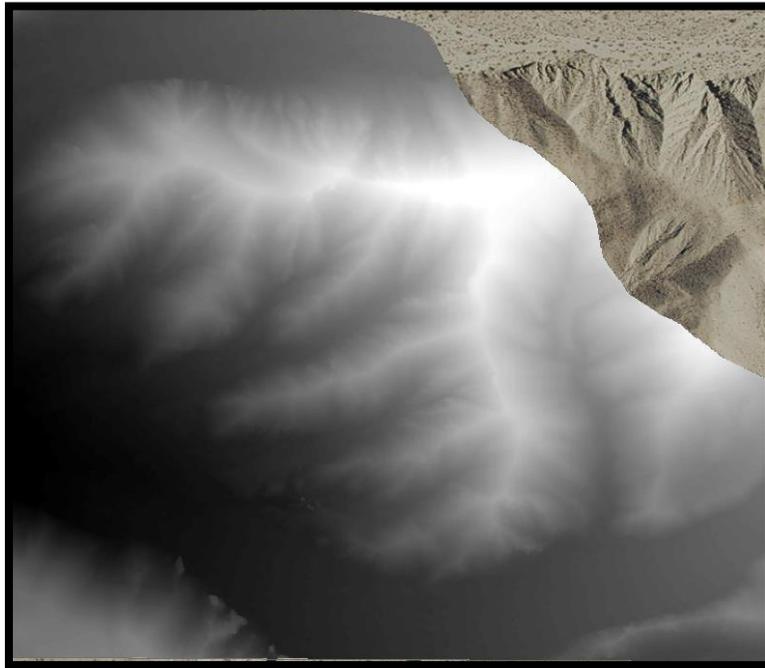
$X_{\min} = 567632.239$ $Y_{\min} = 3741008.882$ $X_{\max} = 568141.062$ $Y_{\max} = 3741485.939$

Painted Hill Fan:

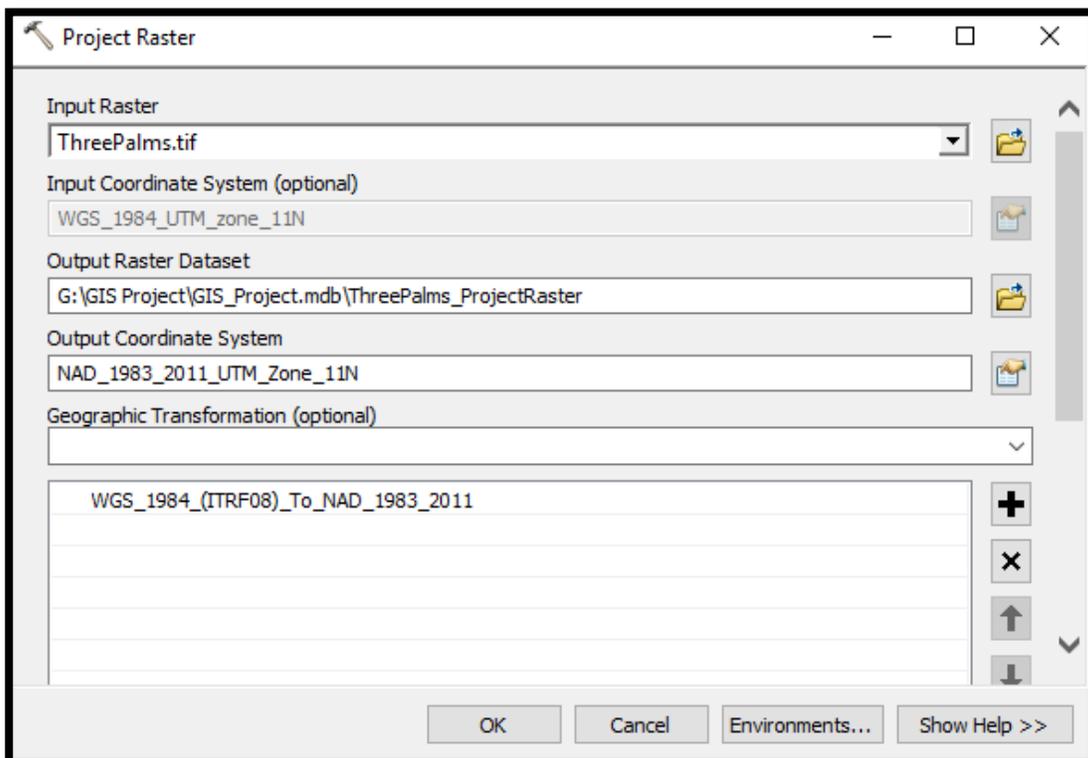
$X_{\min} = 535100.437$ $Y_{\min} = 3755788.363$ $X_{\max} = 535208.649$ $Y_{\max} = 3755960.972$



- 3.) After you have selected these regions, scroll down and accept the defaults for steps 2-5. Enter an appropriate job title and your email. The data generation might take a minute or so. If you leave the page, the DEM results will send to your email, so you can recover them there. Once you are at the results page, under “Download Job Results” select “Download DEM TIN”.
- 4.) Since this is a tar.gz zipped file, you will need to extract these files into your desired workspace twice—once for unzipping the file folder and another time for extracting the tin.tiff into the workspace. Doing all of this on the Windows File Explorer is possible, but I have found it easier to use a third party program (such as 8zip or 9zip) to perform the extracting duties.
- 5.) Okay! You now have your complete, georeferenced LiDAR DEM. You may want to rename them in your workspace (because “output.tin.tiff” and “output.tin.tiff (1)” might be confusing to work with.)
- 6.) Open ArcMap, drag the DEM’s into the Table of Contents from your workspace in ArcCatalog. Click add data, add basemap, and add imagery. This will provide a background satellite imagery basemap that can confirm that your downloaded LiDAR DEM is properly georeferenced.



- 7.) The DEM will be georeferenced, but it might not perfectly project onto the basemap imagery without some preprocessing. If this is the case, on the Search menu, click the “**Project Raster (Data Management)**” tool. Select the DEM as your input raster, you will update the projected coordinate system to NAD 1983-2011 UTM Zone 11.

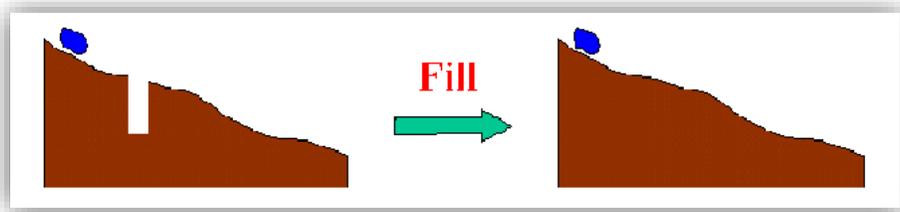


1.2 ArcHydro: Basin and Catchment Area Isolation.

For the next section, we are going to want to utilize the tools provided by ArcHydro to take the DEM and have it isolate a catchment area basin based on flow accumulations from flow directions. This is a very powerful tool that you can use with high resolution DEMs that will automatically delineate the catchment area if the tools are used in the right order. To isolate the catchment area using ArcHydro, complete the steps below:

Before going through the steps make sure the Spatial Analyst License is checked (**Click on Customize-> Extensions-> check Spatial Analyst, 3D Analyst, OK**)

- 1.) Most DEMs (especially hi-res LiDAR DEMs) are going to have artificial gaps, or pits, from when they were first created. The cells that make up a pit have no downstream cells around it, so unless these pits are filled, they will become sinks and will isolate some portions of the watershed and will influence their flow accumulations. It is important to produce a new DEM that will fill these pits by increasing the elevation to the pour point until that pit will drain to a neighbor.



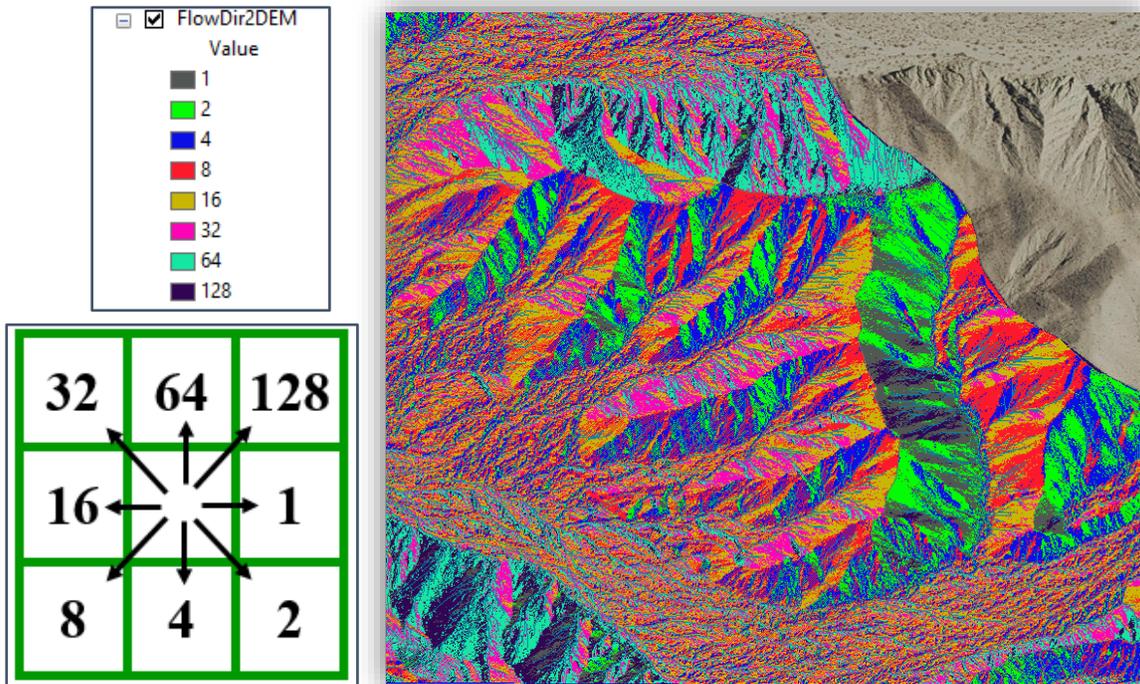
Open Spatial Analyst Tools-> Hydrology-> Fill
Input the projected DEM, leave the z-limit blank.

The resulting raster will look very similar to the original DEM.

- 2.) Next, we want to find the flow direction of the raster cells, that is, the accumulation of directions of lowest neighbors adjacent to a raster cell.

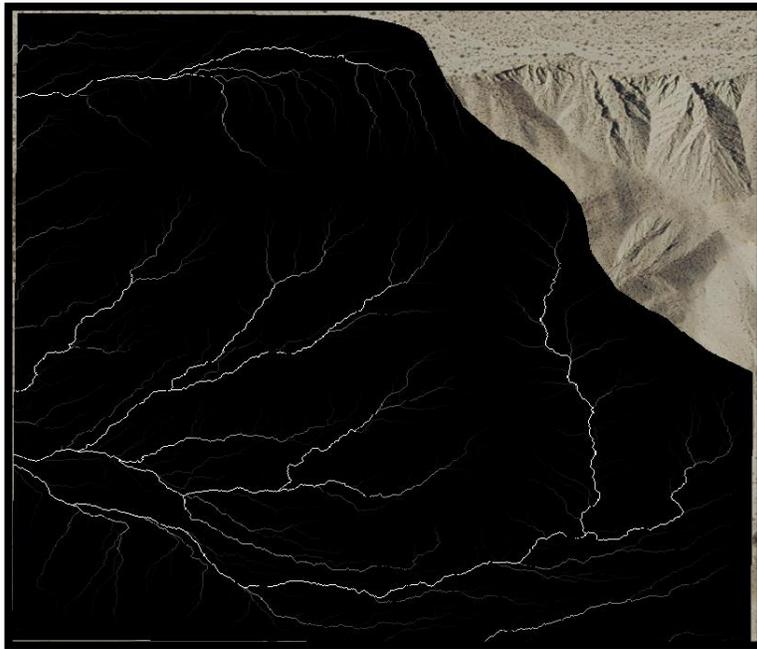
Open Spatial Analyst Tools-> Hydrology-> Flow Direction
Input the filled DEM raster, check the box that says "Force all edge cells to flow outward",
leave the output drop raster blank.

The flow direction raster will look like the raster shown below, with an 8 value raster table with the values, 1,2,4,8,16,32,64, and 128. These numbers correspond to the flow direction explained below.



3.) Next we need a raster of the accumulations of the flow directions (simply put, a flow accumulation raster). This will be represented as a raster a continuous symbology that might not look like there is much data, but can be brought out by going to changing the Stretch from "Percent Clip" to "Standard Deviations" (Symbology tab in Layer Properties)

Open Spatial Analyst Tools-> Hydrology->Flow Accumulation
Input the flow direction raster, accept the rest of the defaults.



- 4.) We are then going to have to go back to the flow direction raster to find the basins for which the flow directions correspond to. This will create a raster outline of the different drainage basins in the area. To isolate the basins:

Open Spatial Analyst Tools-> Hydrology->Basin

Input the flow direction raster, accept the rest of the defaults.

- 5.) We will then need to convert this raster into multiple vector polygons, so we can make the desired drainage basin a selectable feature.

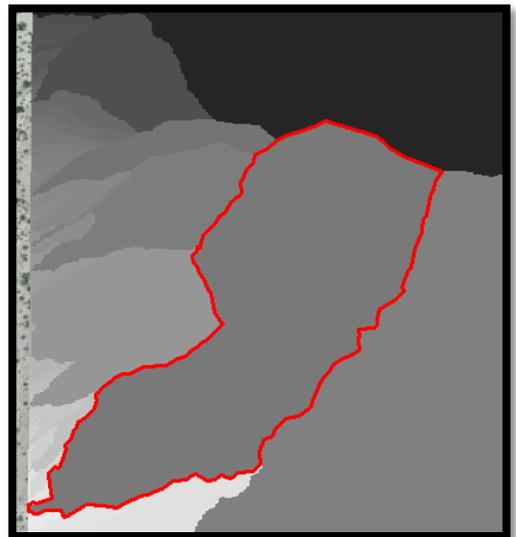
Open Conversion Tools-> From Raster->Convert to Polygon

Input the flow direction raster, accept the rest of the defaults.

Name the flow accumulation raster "FlowAccXX" XX= PH for Painted Hill, TP for Three Palms



- 6.) To select the desired catchment area (shown below), click **Select Features** and click the polygon. There are two selectable basins in the Three Palms fan (West Fan- shown here, and Central Fan) and one basin in the Painted Hill fan. Then **select the Clip tool**, your input feature will be the new basin vector polygon you created in the previous step, if the catchment area is still selected (as it should be) the Clip feature will automatically set itself. Name the new layer appropriately.



- 7.) **Open Spatial Analysis-> Map Algebra-> Raster Calculator**
Input "FlowAccXX > 50" in the SQL query.

Name the output raster "FlowAccXX50". By performing this raster calculation, we are selecting the raster cells that have over 50 raster cells accumulating their flow into them. You can play around with this number—since we have very high resolution data, one could theoretically get a very accurate flow accumulation model by selecting a number as low as 10, but the data looks rather congested (and blocky) if you do this. Inversely, if this number is too the output raster calculation will not model the hydrologic network as detailed as it possibly can. I've found that with a 1-m resolution DEM, the values 50-80 produce a detailed flow accumulation raster without being too blocky.

- 8.) **Open Conversion Tools-> From Raster-> Covert to Polyline**
Input the "FlowAccXX50" raster, accept the rest of the defaults



This will convert the flow accumulations into a selectable (and as we will see, "clippable") raster polyline feature.

- 9.) We will then need to clip the newly acquired vector flow accumulation layer to just the desired catchment area. To do this:

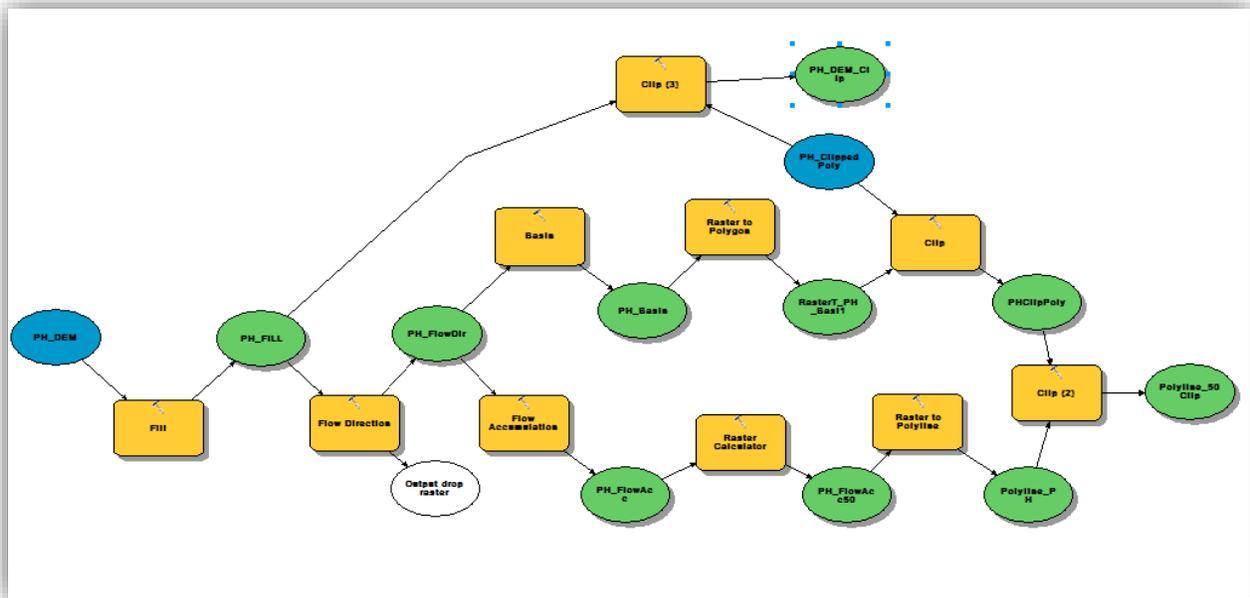
Open Analysis Tools-> Extract-> Clip

The input feature will be the flow accumulation vector; the clip feature will be the clipped catchment area vector polygon (acquired in step 6). Accept the rest of the defaults.

10.) For a final map, I clipped the DEM layer the same way that the flow accumulation vector was clipped, and I used that as a backdrop for the clipped flow accumulation vector. (See Final Maps 1 and 2). To do this:

Open Data Management Tools->Raster->Raster Processing-> Clip

Input feature is the filled LiDAR DEM, Output extent is the Clipped Catchment Polygon, CHECK THE BOX that says "Use Input Features for Clipping Geometry", this is important



1.3 Measure the perimeter, area and aspect ratio for the catchment areas.

To measure the surface length of the catchment area, right click on the clipped basin vector layer and open the attribute table. The attribute table will contain length of the perimeter and the surface area in meters and square meters respectively. To calculate the aspect ratio of the fan, use the measure tool on the main tool bar. In the Measure tool, click the right most group down menu and change the measurement from "Planar" to Geodesic". Measure the longest axis of the fan and a perceived average of the shortest axis

Results for the alluvial fan catchment area statistics are shown below.

Catchment Area Meas.	Perimeter (m)	Area (m)	Aspect Ratio
Three Palms (West Fan)	836.01	25871	2.879
Three Palms (Cent. Fan)	1036.22	48628.98	2.137
Painted Hill	560.70	12240.06	3.087

1.4 Using Topographic Position of Index (TPI) to determine the surface roughness of the catchment areas.

Topographic roughness can be determined in many different ways, depending on the calculation used to measure it. It based on a standard deviation of elevation, standard deviation of slope, convexity of slope, variability of plan convexity, or other factors. It should be obvious to note that the resolution of the DEM is a crucial factor when producing an accurate surface roughness calculation. To measure the surface roughness of the desired catchment area, keep the catchment area vector file that was isolated in section 1.2. We will characterize surface roughness by its relative topographic position, or Topographic Position of Index (TPI). This is both a terrain ruggedness metric and a local elevation index, which means that each pixel of the TPI is characterized with respect to its local neighborhood (this really brings out the powerful DEM resolution we have available).

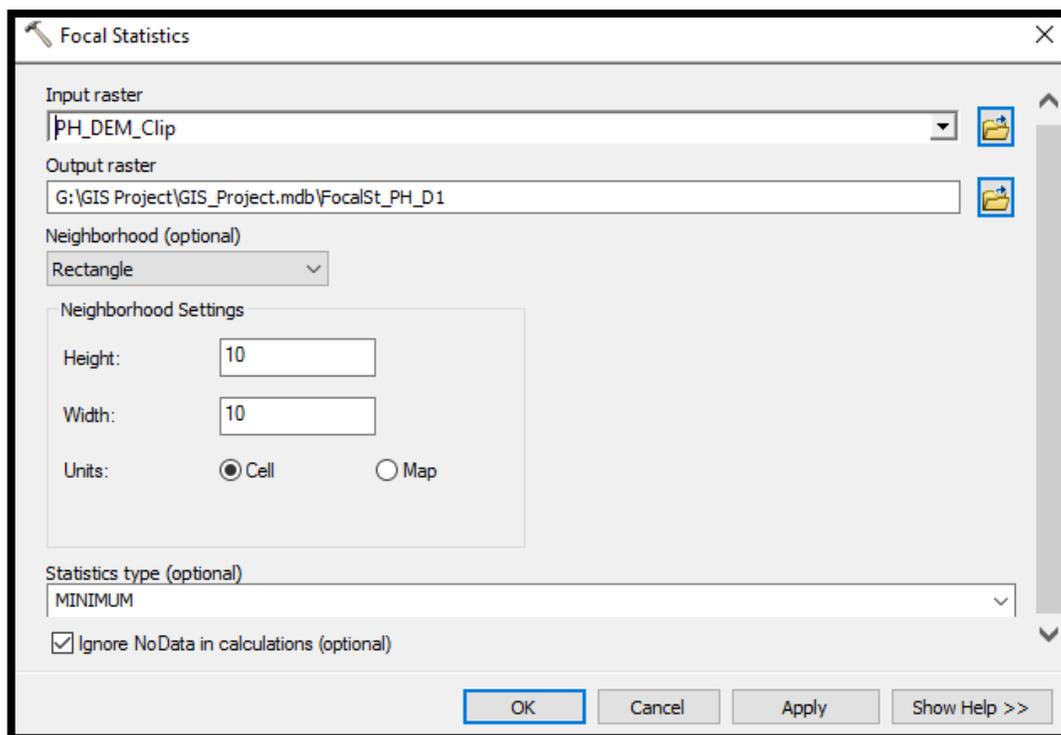
To characterize roughness based on TPI, follow the steps below:

- 1.) Create a minimum elevation raster

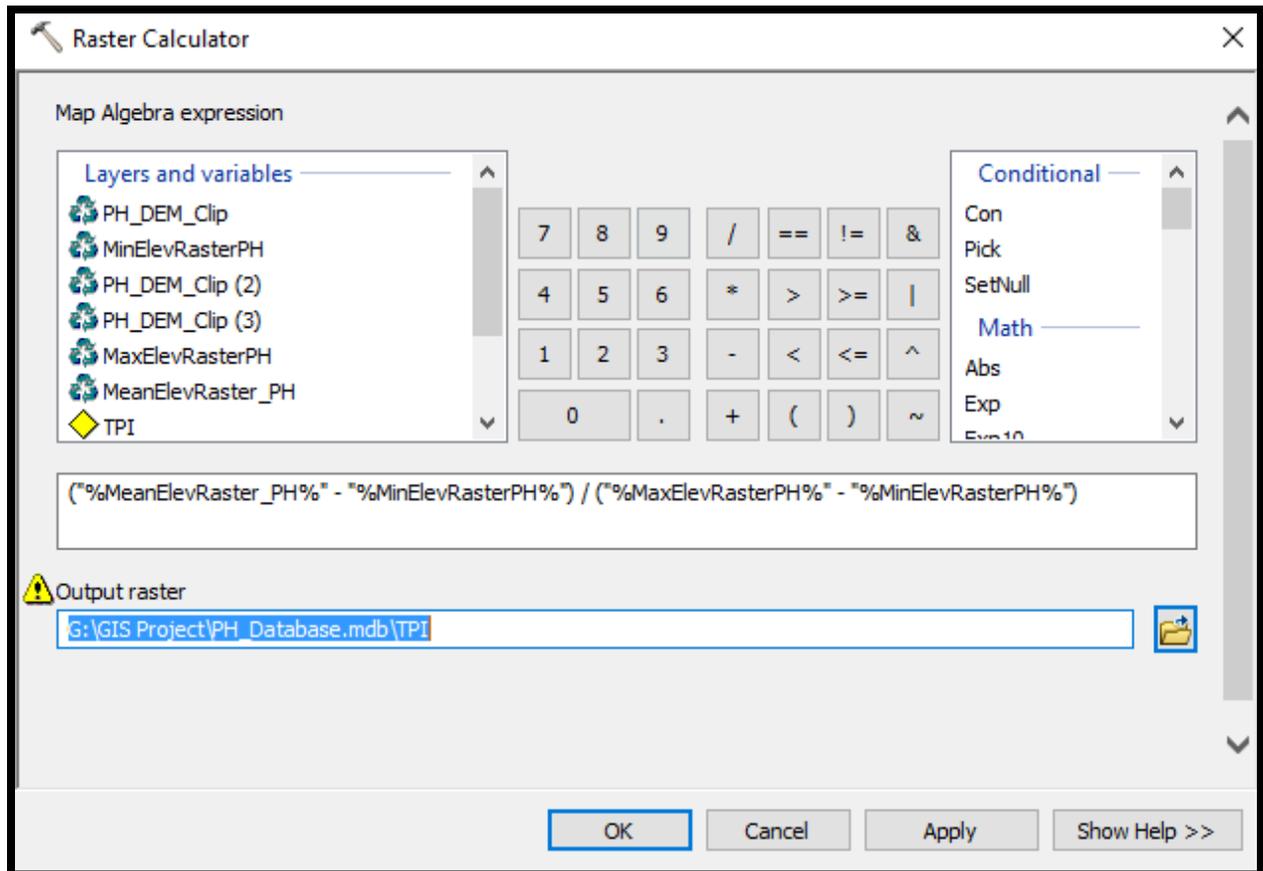
Spatial Analyst Tools-> Neighborhood->Focal Statistics

The input will be the clipped DEM of just the desired catchment area, name the output appropriately, leave it on RECTANGLE, change the height and width to 10x10, change statistics type to MIN.

Note: you can change the 10x10 cell neighborhood and get different results- but since we have very good DEM resolution I do not anticipate that changing this value would yield dramatically different results.



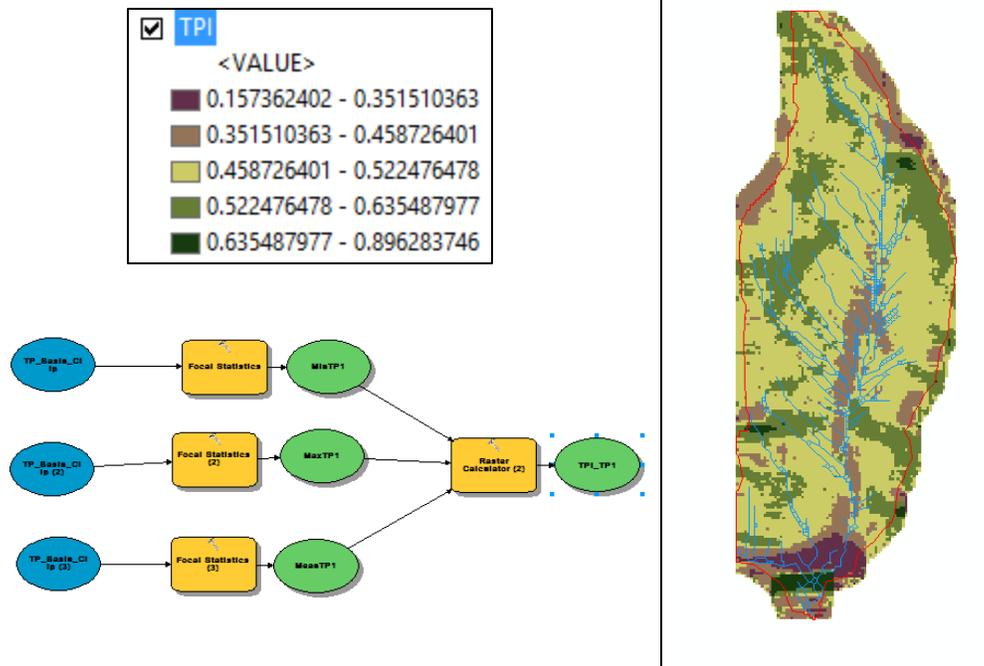
- 2.) Create a maximum and mean (smoothed) elevation raster—repeat the steps above but put the appropriate raster type in the menu. Note- smoothing is not required, but it generally produces a more spatially coherent, interpretable roughness raster.
- 3.) Pull up Raster Calculator- type in the equation shown below.



- 4.) The resulting raster is the TPI- and will contain values from 0-1 (with 1 being the roughest) Try displaying this output in a 5-class color scheme (change from Stretched to Classified on “Symbology” Tab in Layer Properties) with Natural Breaks (Jenks) an example is shown below- all three catchment areas are shows in the final maps below.

- 5.) Write down the mean, range, and standard deviation of the TPI. Results shown below.

Roughness Statistics	Mean	Range	Standard Deviation
Three Palms (West Fan)	0.489	0.5842	0.0580
Three Palms (Cent. Fan)	0.496	0.6910	0.0619
Painted Hill	0.493	0.7389	0.0655



1.5) Compare these statistics to the variability of the fan ages with respect to the minimum ¹⁰Be age. Quantify results and show final maps.

Below is the raw age data for both fans (TP and PH), keep in mind that the sample ages for the TP fan are good for only the central fan, the west fan does not have an age dataset.

Three Palms

Painted Hill

Sample TP_Central	age	external error
1	6532	647
2	20118	2000
3	24302	2419
4	9786	970
5	10711	1062
6	12052	1196
7	5231	518
8	21784	2167
9	15821	1571
10	16823	1671
11	6399	634
12	15146	1504
13	13267	1317
14	14461	1436

Sample (PH)	ages	uncertainties
1	4773	971
2	5735	1138
3	9147	1849
4	6789	1504
5	6570	1267
6	9197	1710
7	6473	1340
8	5132	1093
9	8303	1724
10	2429	614

Here are some vital statistics about each dataset. For variability we will be looking at the age range with a normalizing factor of 2, since the Three Palms fan has an interpreted age that is double that of the Painted Hill fan (5 ka and 2.5 ka, respectively).

Three Palms Fan

Mean Age	Mean Error	
13745.2143	1365.14286	
Range	Min Age	Normalized Range
19071	5231	9535.5

Painted Hill Fan

Mean Age	Mean Error	
6454.8	1321	
Range	Min Age	Normalized Range
6718	2429	6718

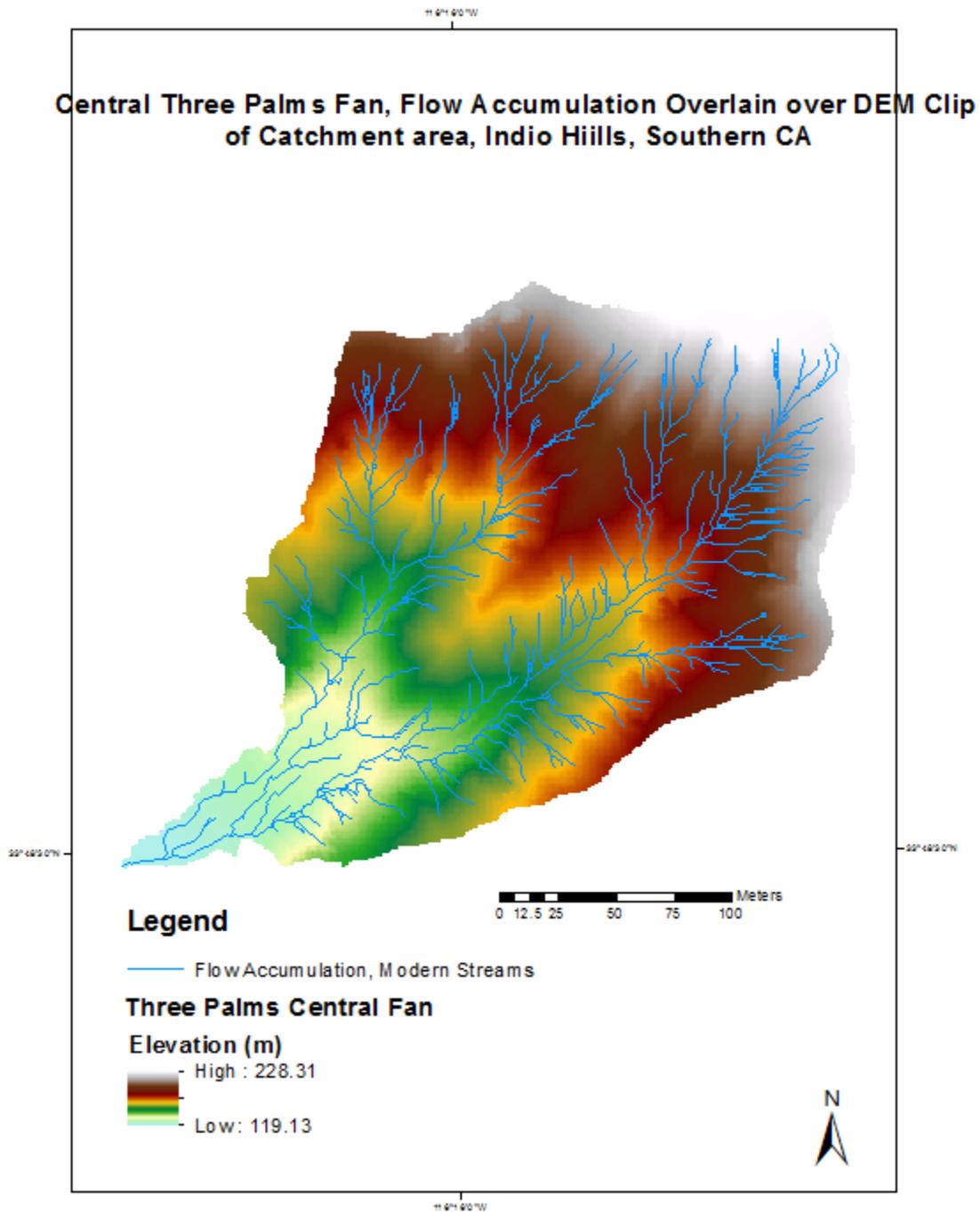
Next, I compared the normalized ranges for both fans to the catchment area morphology roughness measurements. Since we have only analyzed two fans in this study, the results do not provide a powerful relationship that tells us much about how catchment area morphology and surface roughness affect cosmogenic age variability. However, as more LiDAR imagery becomes available for arid alluvial fan catchment areas, this method will be useful in analyzing more of these scenarios.

For the Central Three Palms fan, the Normalized Range was 9535.5 years, with a catchment area perimeter of 1036.22 meters, an area of 48628.98 square meters, an aspect ratio of 2.137, and a mean surface roughness TPI of 0.496, but with a TPI range of 0.6910. For the Painted Hill fan, the Normalized Range was 6718 years, with a catchment area perimeter of 560.70 meters, an area of 12240.06 square meters, an aspect ratio of 3.087, and a mean surface roughness TPI of 0.493, but with a TPI range of 0.7389.

This results show that the smaller catchment area although with a higher aspect ratio and a slightly more variable roughness had a less variable age dataset. As mentioned before, comparing these two catchment areas do not provide a lot of information, but the method delineated in this project can be used for analysis of these fans for future workers.

Final Maps

Central Three Palms Fan, Flow Accumulation Overlain over DEM Clip of Catchment area



Surface Roughness measurement using Topographic Position Index of the Central Fan

