Mine Contamination at the California Gulch Superfund Site by Leadville, Colorado

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May 5, 2016

Background:

The goal of this project was to calculate the volume of tailings piles leftover from past mining outside of Leadville, Colorado. The area selected is called the California Gulch Superfund site and has been a Superfund site since 1983. There is great interest in studying tailings piles because they may contain harmful substances leftover from the extraction of minerals. Especially in the early days of mining, when they were not as many regulations, harmful substances would get dumped into the tailings and over time these would leach into the ground. These tailings piles may also collapse during heavy rains, so ensuring that tailings are built at safe angles and heights helps ensure that this does not occur. There have been many companies that have operated in the area over the years and the EPA did reach settlements with two of them. The EPA reached a settlement with Newmont and ASARCO for roughly $10 million each in 2009, unfortunately ASARCO filed for bankruptcy due to the fact that 20 of its mining sites/smelting sites are Superfund sites currently.

The study is just a first order approximation of the California Gulch superfund site. Many assumptions had to be made and no hazard areas could be calculated. As stated above these piles may experience slope failure during rain storms, so release of containments may be highly variable. The Stray Horse Gulch River (main river that would be contaminated) flows by the outskirts of Leadville and then into the Arkansas River. A paper by Velleux et. al calculates flooding simulations and finds in a hundred-year flood CCUs (index that measures harmful concentration) will spike to very high levels especially in regards to zinc. Although this is very disconcerting the authors do point out that this is a maximum concentration and they do not know how long dangerous levels would persist. My volume study should be the basis for a much larger study that would analyze the whole historical area for total volume of tailings piles. The total volume of the area would then generate a good estimate of what to be expected in worst case flooding scenarios.

Acquiring Data:

The first step in the project was to select an area of Colorado that had high precision LIDAR data. The availability of LIDAR data must then match the availability of historical mines. The mine data is available from the Mineral Resource Data system. Although the mine data is supposed to just be Colorado, it does display information about surrounding states. The LIDAR availability, as shown below, is available from the National Map viewer on the USGS website. Matching up the mines to the LIDAR just consisted of looking for mine concentrations that would fall within the LIDAR imagery, and then looking at the attribute table for the mines to see if the mines operated for a while, with mines that were in production for longs periods of time given preference. Once further research was completed Leadville was found to be a Superfund site, so the area around Leadville was selected.

Once the area around Leadville was selected the corresponding LIDAR data was downloaded. Ultimately, 5 LAS datasets were downloaded along with a 1/3 arcseond DEM which will be used later on to calculate volumes. All files downloaded were in UTM Harn 13N coordinate system.

USGS map viewer: http://viewer.nationalmap.gov/basic/

Mineral Resource Data System: http://mrdata.usgs.gov/mrds/select.php

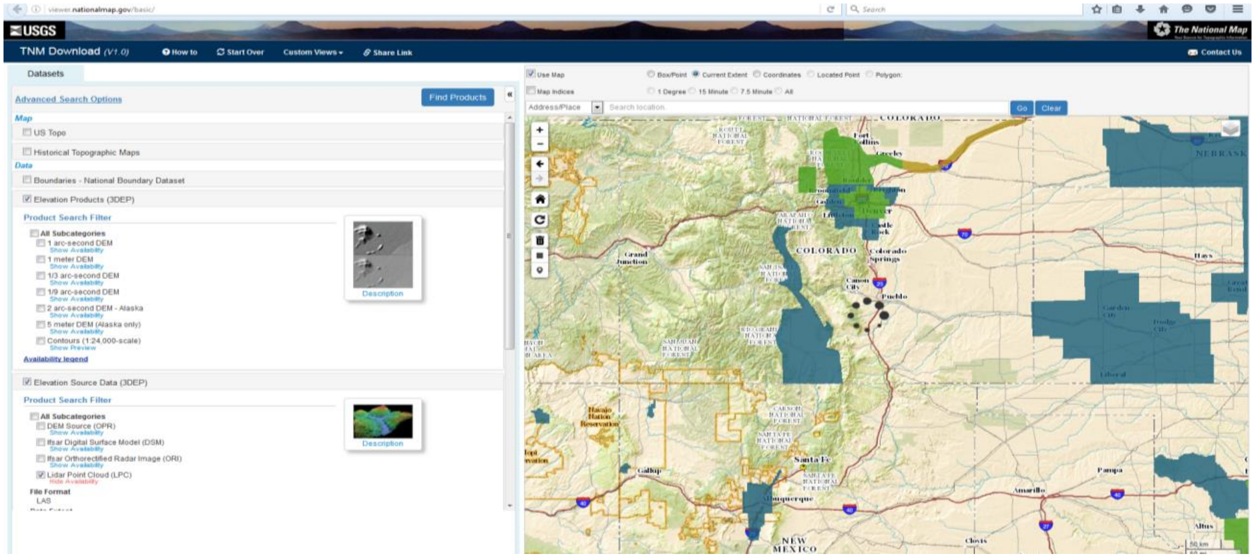
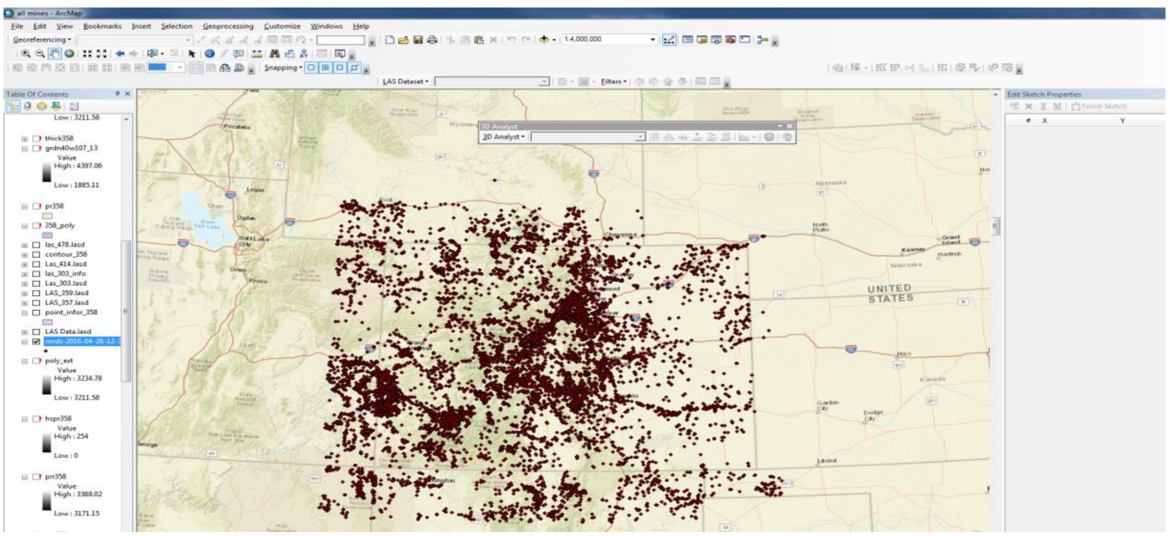
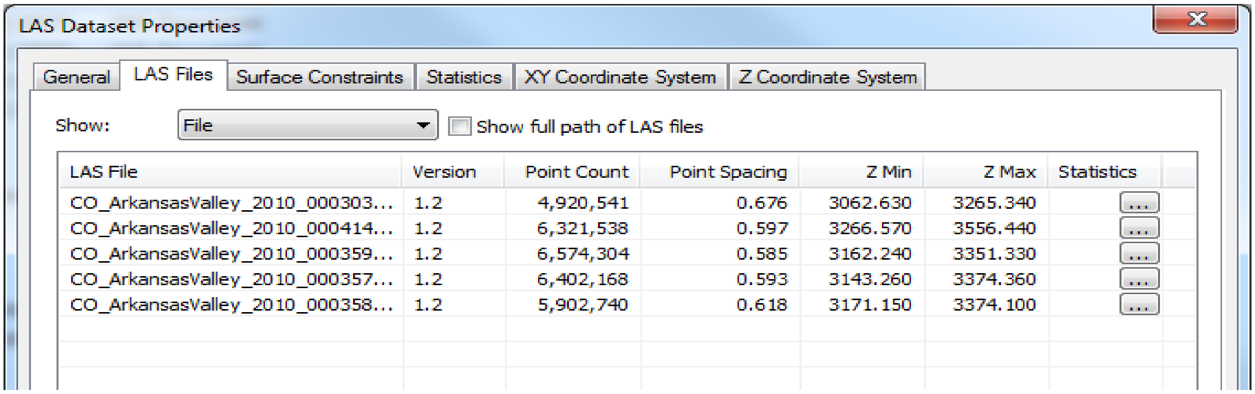


Figure below shows mines in Colorado and surrounding states.



Data Analysis:

Once the LAS files were downloaded they had to be combined into one single LAS database file. Furthermore, point information queries had to be run in ArcMap to calculate the point spacing, so that a cell size could be calculated later on. The query returned a point spacing value of .59 meters (corresponding to .59 meters between returns). Once the LAS dataset was added to ArcMap a Las to raster query was run.



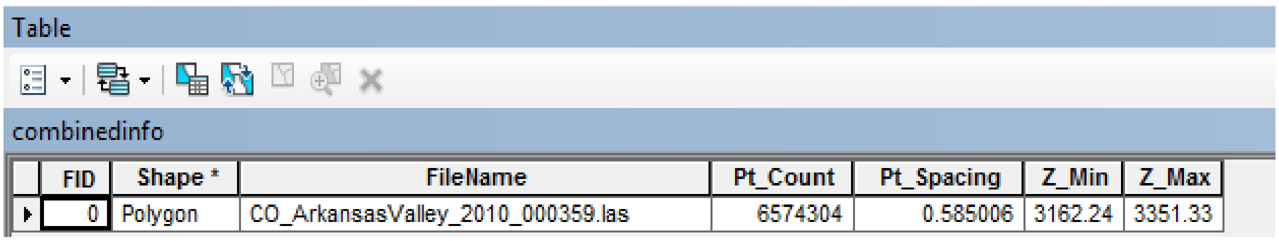
LAS Dataset Properties

General | LAS Files | Surface Constraints | Statistics | XY Coordinate System | Z Coordinate System

Show: File

Show full path of LAS files

LAS File	Version	Point Count	Point Spacing	Z Min	Z Max	Statistics
CO_ArkansasValley_2010_000303...	1.2	4,920,541	0.676	3062.630	3265.340	...
CO_ArkansasValley_2010_000414...	1.2	6,321,538	0.597	3266.570	3556.440	...
CO_ArkansasValley_2010_000359...	1.2	6,574,304	0.585	3162.240	3351.330	...
CO_ArkansasValley_2010_000357...	1.2	6,402,168	0.593	3143.260	3374.360	...
CO_ArkansasValley_2010_000358...	1.2	5,902,740	0.618	3171.150	3374.100	...

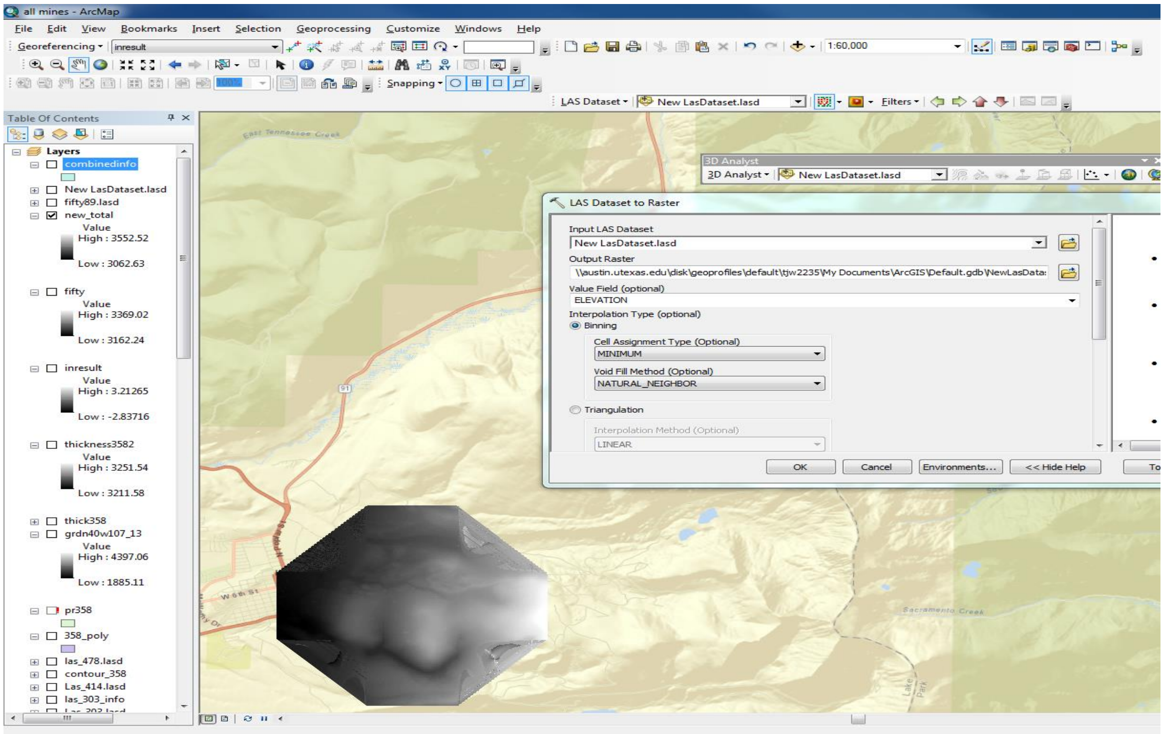


Table

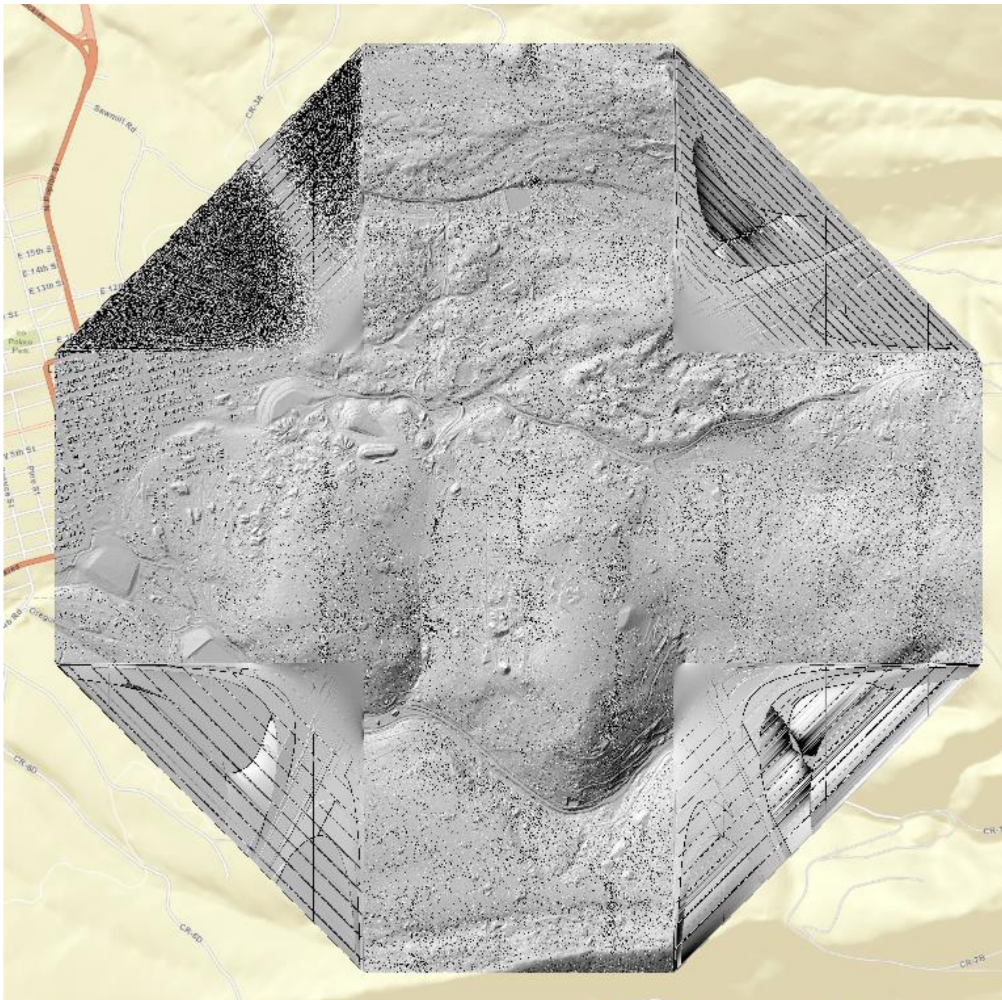
combinedinfo

FID	Shape *	FileName	Pt_Count	Pt_Spacing	Z_Min	Z_Max
0	Polygon	CO_ArkansasValley_2010_000359.las	6574304	0.585006	3162.24	3351.33

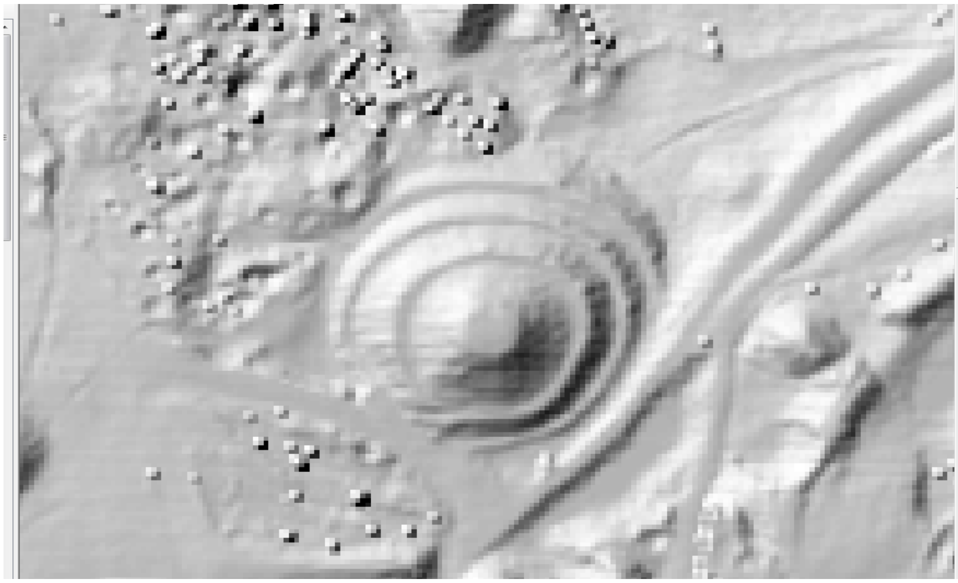
The query combined all of the Las files in the dataset into one Total raster. The LAS to raster query was run using Minimum for the cell assignment and natural_neighbor as the void fill method. This ensured that only the lowest values from the cells were selected and each cell would have a proportionate weight based on near-by cells. The sampling value was set to 1.5 meters due to the fact that the point spacing was set to .58. This 1.5-meter value corresponds to roughly 2.5 times the spacing value, to ensure correct values were calculated. See below for query and resultant product. Once the raster was created the projected coordinate system was changed from NAD_1983_HARN 13N to NAD_1983 13N (coordinate system the data frame was set to).



Once the Raster was created a hillshade query was run which turned the raster into a hillshade that allows elevation changes to be noticed more easily. This was completed due to the fact that the area of the tailings piles needs to selected by hand, so the hilshade allows for better interpretation. As a side note it is very easy to see the outline of the five combined rasters due to the fact that when the las to raster query was run the processing extent environment was not selected to the correct setting, so the program interpreted unknown areas between datasets. These “unknown areas” can be ignored due to the fact that the only tailings of interest are in the five correctly calculated areas. Also of note are the many “dots” that occur which are lodgepole pine trees.



Once the hillshade was created a polygon shapefile was created with a NAD_83_UTM 13N coordinate system. The mine tailing areas were added to this polygon. To ensure that the mine tailings were selected and not small hills, a world satellite imagery basemap from ESRI was added. Toggling between the hillshade and the satellite imagery was completed to ensure selection accuracy. Tailings piles were selected due to their unusual topography and lack of trees present on piles. Figure below shows a zoomed-in tailings pile in the hillshade.



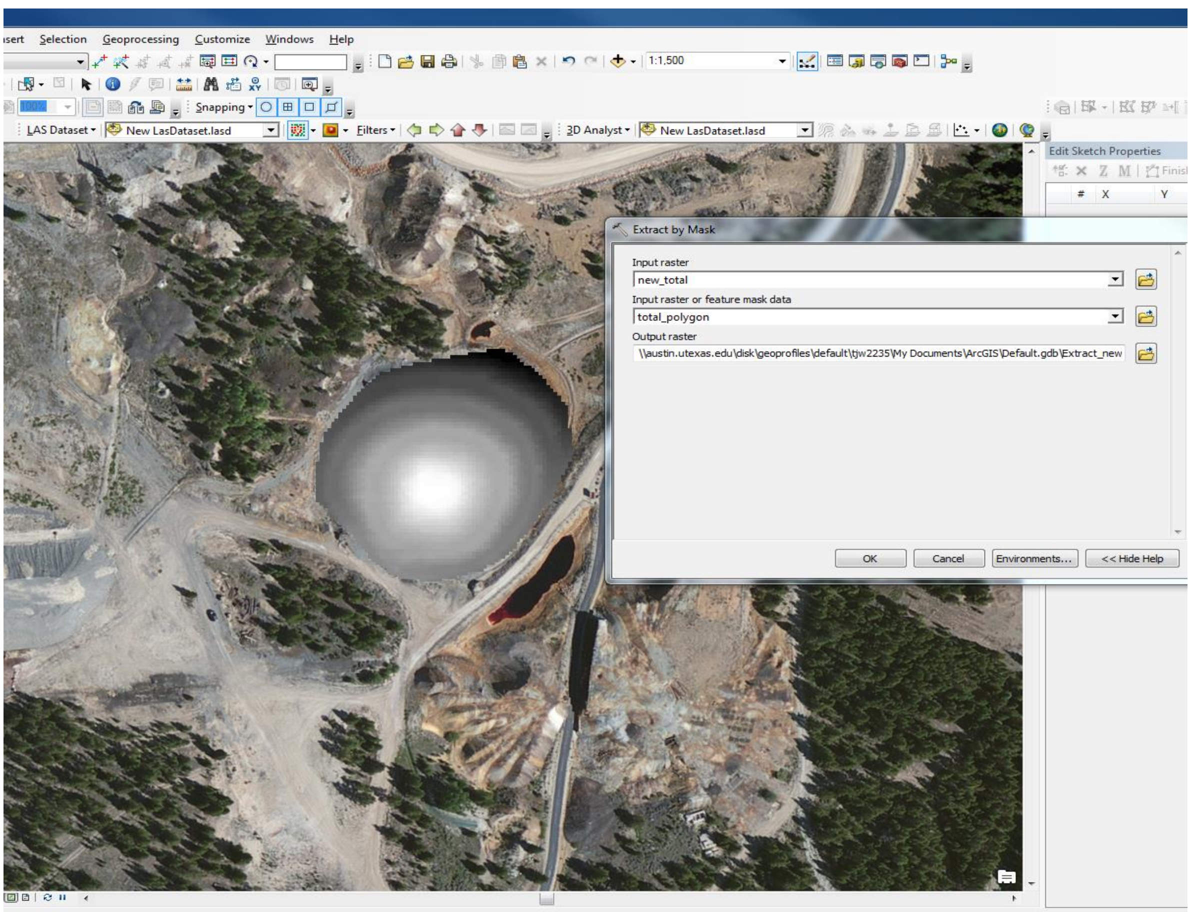
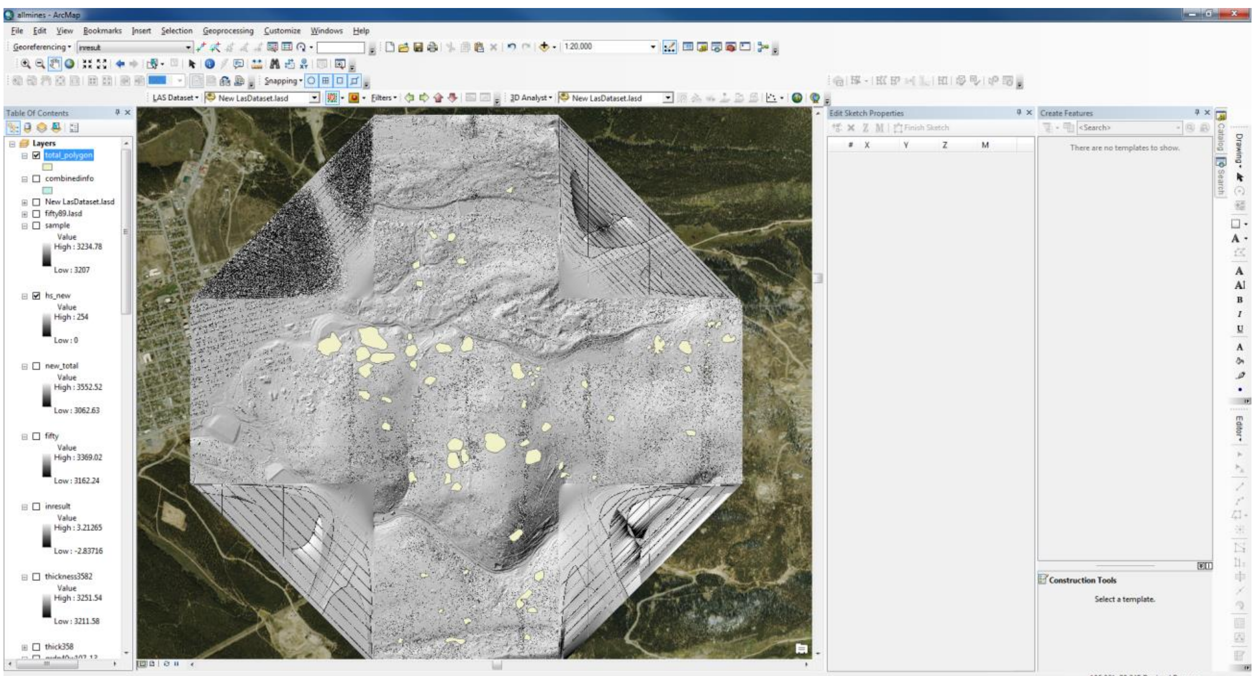
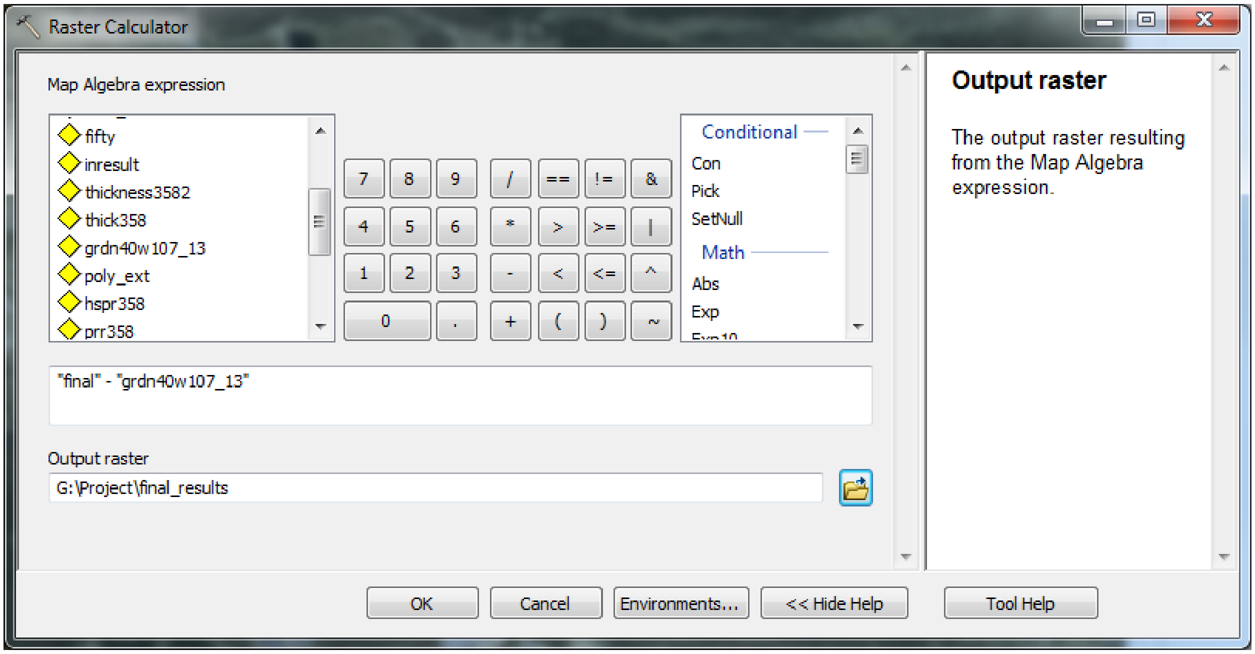


Figure above shows extracted mask of single tailings pile. Polygon matches outline of pile very closely in both hillshade and satellite. Polygon was extracted out of Total raster. This process was completed for many polygons. All 66 polygons, as shown below, were in one shape file and extracted as a group; this example was completed to show the process. There are more “mine tailings” on the Western side of the hillshade, but those tailings most likely correspond to gravel piles and one garbage dump, especially considering how close to the city those “tailings” are. There are also numerous very small tailings scattered about that were too hard to draw a polygon around. Also, some “tailings” are not tailings and are instead just trash/equipment heaps.

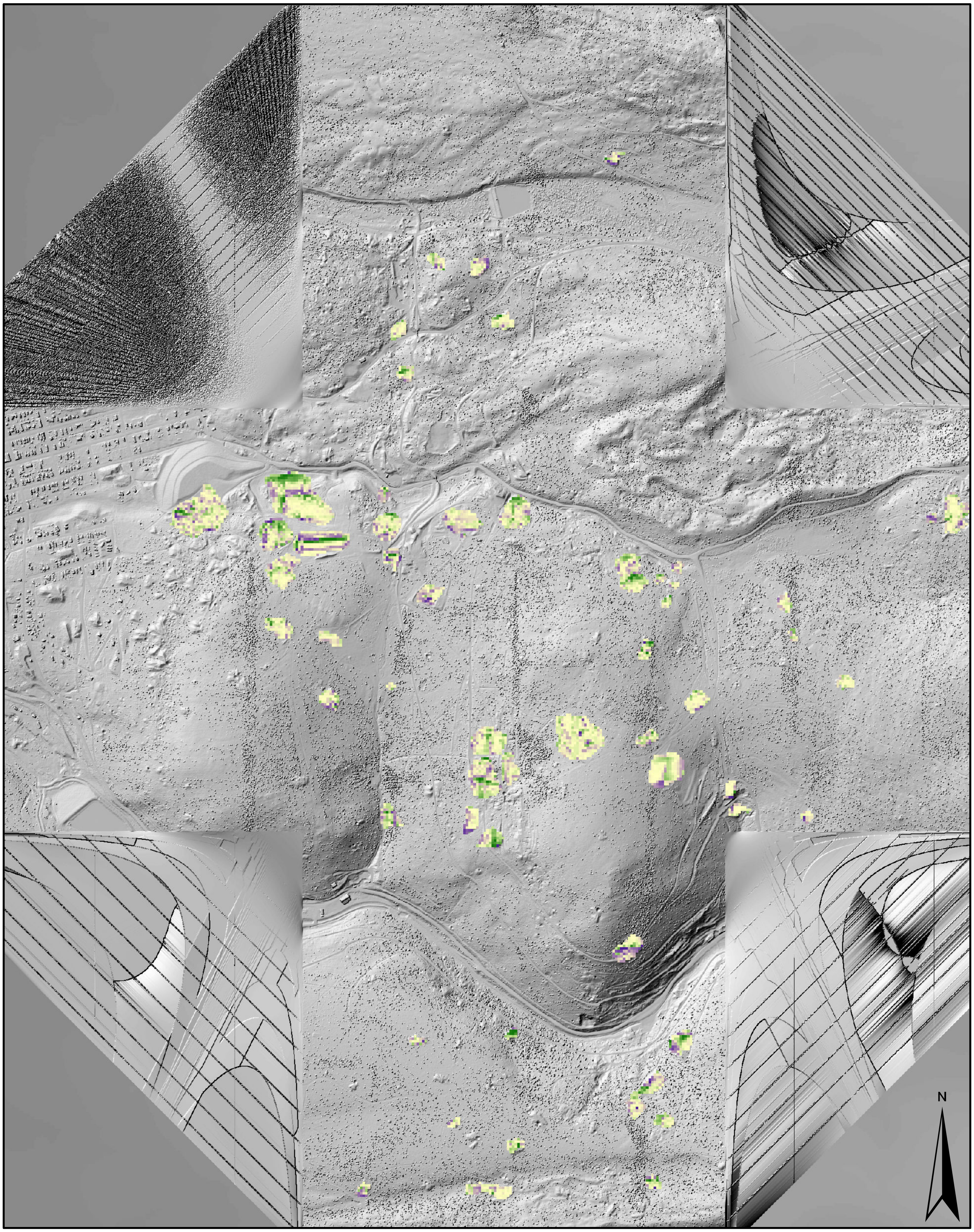


Once the polygons were created the extract by mask query was run resulting in all the polygons being extracted from the Total raster. This resulted in an extracted raster having just the polygons left with values ranging from 3500 meters- 3161 meters. This extracted raster was then subtracted from the 1/3 arcsecond DEM using the raster calculator. The arcsecond data does not include the mine tailings, so the calculations just calculate the volume of the tailings that have been built up. As a note there is a 1/9 arcsecond DEM available for the area, but that is directly based on the LIDAR data, so this would not help in these calculations.



The results from the calculations resulted in a raster_calculation with values ranging from 10.4 meters to -48 meters. The -48-meter value is possible because some pits were accidentally included in some of the polygons, which would greatly lower the normal elevation. (Consult attached map to see the highly varied terrain. Map shows post raster-calculator results.) Although most of the tailings are just a couple meters above the DEM, the map does convey how common these pits next to the pilings are. There is just one polygon that actually reaches -48 meters, most are only a couple meters deep. After the calculation was run a surface volume calculation was completed on the raster_calculation and the plane height was set to 0 meters, to just include the tailings height. Anything above zero was assumed to be part of a tailings pile.

California Gulch Superfund Site

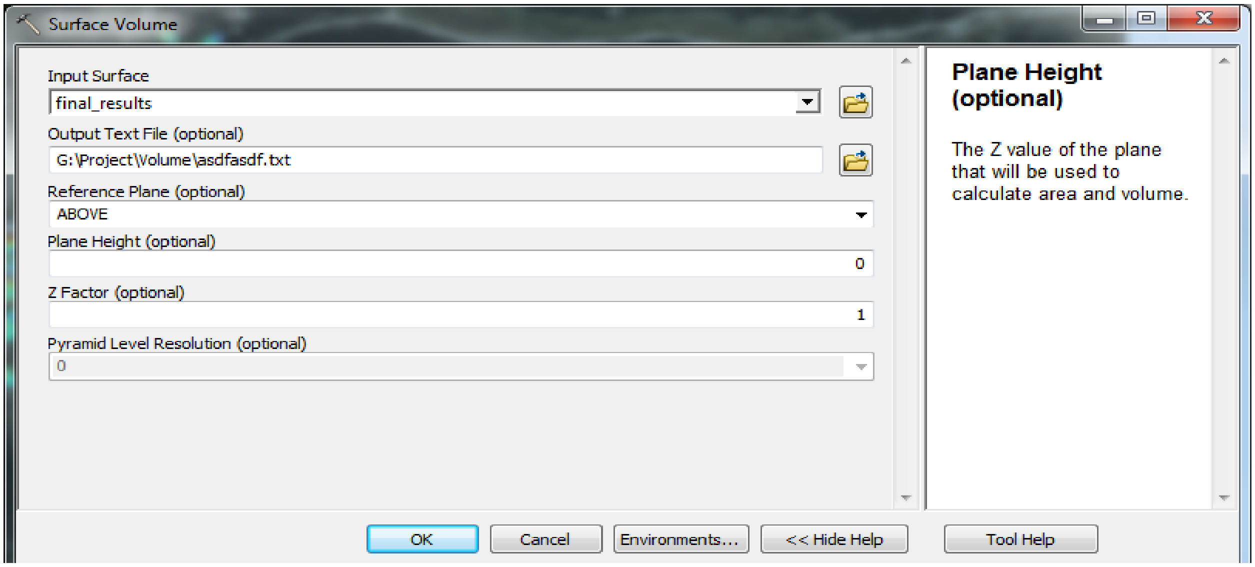


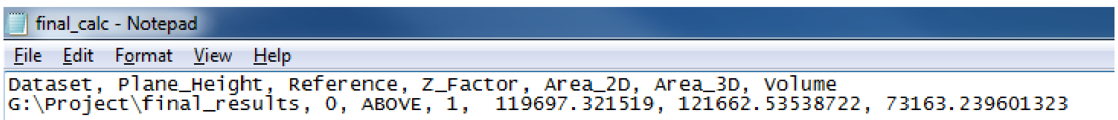
0 0.275 0.55 1.1 Kilometers

Raster calculation
High : 10.3765
Low : -48.304

Hillshade
High : 254
Low : 0

1/3 DEM
High : 4397.06
Low : 1885.11





The resulting text file, shown above, displays the total calculated volume of 73,196 m^3 of tailings. Two papers, Swayze et. al and Velleux et. al, took samples from tailings in the area and were utilized to calculate estimated leftover material. Swayze had an average of 1340 ppm for Zn, Cu, Cd, Pb, Co, and Ni.

$$\frac{1340mg}{L} * 73196m^3 * 1000\frac{liters}{m^3} * 10^{-6}\frac{kg}{mg} = 98{,}083\ kg.$$

Velleux et. al had an average value of 36.5 mg/kg for cadium, 493 mg/kg for copper, and 6530 mg/kg for zinc. Porter et. al states 1.36 metric ton per cubic meter (dry) is a commonly used mine tailings value for copper mines, so this value was applied for total tailings mass for the selected tailings. Although this is not exact, similar minerals were mined at each site, so it is a good approximation.

$$73{,}196\ \text{m}^3 * 1{,}360\frac{kg}{m^3} * 36.5\frac{mg}{kg} * 10^{-6}\frac{kg}{mg} = 3{,}633\ kg\ Cd$$

$$73{,}196\ \mathrm{m}^3 * 1360\,\frac{kg}{m^3} * 493\,\frac{mg}{kg} * 10^{-6}\,\frac{kg}{mg} = 49{,}076\ kg\ Cu$$

$$73{,}196\ \mathrm{m}^3 * 1360\,\frac{kg}{m^3} * 6530\,\frac{mg}{kg} * 10^{-6}\,\frac{kg}{mg} = 650{,}039\ kg\ Zn$$

As can be seen from the results roughly 98,000 kg of leachable materials was calculated using Swayze values and roughly 702,748 kg of leachable material was calculated from Velleux. The large discrepancy is probably due to the zinc value and may just be due to different tailings selected for measurement. This just reinforces the fact on how varied these estimates may be. Since mining started in the area in the 1860 there has been a large change in how tailings have been handled, so some tailings may be quite safe, while others may have very high concentrations of these leachable materials. The EPA states that site remediation is being completed, but at the same time it states on its website that human exposure status is not under control and that the site is not ready for wide-spread use. The EPA does provide free-lead level testing throughout the area and will continue to do so indefinitely, so that ensures that if tailing collapses occur you can test your blood. The EPA encourages pregnant women and children to have their lead-levels continually tested if they reside in Leadville.

This study was conducted to calculate possible values for a small section of California Gulch. There is a minimum estimate of 2000 mine tailings in this area, and only 66 tailings were selected. This was mainly due to the fact that the LIDAR coverage ended in California Gulch, so more work could not be completed. Looking at the satellite maps though, the two main hills selected do contain a very high concentration of large tailings, and these two hills are directly above the city of Leadville, so good inferences from this may be made. Furthermore, 8 miles downstream from the site the California Gulch Creek flows into the Arkansas River.

In conclusion, the results show that there are significant quantities of potentially harmful minerals above a major watershed and a small city. Although massive slope failure of multiple tailings piles is not likely, if during a large rainfall event multiple tailings fail then this would be very hazardous for downstream inhabitants. The zinc concentration in waters is especially hazardous for amphibians and fish, so this will need to be consistently monitored. The surrounding areas and especially the Arkansas River are spawning areas for trout, so they would be very vulnerable to such inflows. Furthermore, if those tailings due fail total suspended solids (TSS) will greatly increase and clog the downstream waterways. Ignoring human sickness due to high lead/Zn levels, solids may persist in the river bottoms for years afterward, potentially resulting in recurring damage whenever a large rainfall event occurs. Considering that the average amount of time to clean up a Superfund site is roughly 13 years or so, public pressure may be needed to ensure that the EPA will finish their 30-year cleanup of the site soon.

Assumptions/Improvements:

There were a couple major assumptions that were made during the course of this project with the main assumption being that all tailings piles are equal. Only two papers were used for calculations and each had significant differences in concentrations. This is a product of different mining (zinc, lead, gold, silver, and copper were all produced here) going on at different times throughout the history of the site. Besides directly sampling each tailings pile for concentrations there really is not any improvement that may be made for this assumption. The mine data from the Mineral Resource Data System is not refined enough to list each mine in the area and tailings piles most likely get mixed together over time. Another assumption that was made was assuming that the polygons only included the tailings piles. There will always be some error in these calculations, and although almost all tailings piles do not have trees/vegetation on them if there were a tree or two this would increase volume calculations slightly.

Some improvements would be to find a better DEM source. I looked at the USGS map viewer data and the Colorado state datum and could not find any data better than 1/3 arcsecond. Improving this resolution would improve the volume calculation. Another improvement would be to complete some sort of hazard map. Since there would be many assumptions made about the tailings piles this hazard map would be very rough, but may display possible areas prone for collapse. If some tailings piles were very steep this may be completed. The main problem with this is then converting kilograms of tailings to ml of contaminations. None of the papers consulted had a direct correlation; they would just measure water samples from rivers after rainfall events. Although contamination levels may be unhealthily high at peak rainfall, levels do drop back to healthy levels very quickly. Calculating this relationship and how far this may travel downstream, especially when the California Gulch River flows into the much bigger Arkansas River is very difficult. Another interesting idea from this project is to do volume of tailings ponds for mines, especially coal mines. Once again the main limiting factor would be the availability of LIDAR data, but if found risk hazard maps should be possible to build. The maps could consist of dam tailings failing and calculating possible flooding areas from the waste/sludge behind the dam. Although these mine tailing dam collapses are rare, when they do occur like in Brazil recently, they are devastating for people and ecosystems. Along with the hazard maps the total volume removed from mountain tops may be calculated along with how much the corresponding valleys are filled up with the sediments from this removal.

References

EPA. “Case Summary: EPA Funded Sites and Communities in the ASARCO Bankruptcy Settlement.” 2009. 5/3/2016.

Porter et. al. “Physical Aspects of Waste Storage From a Hypothetical Open Pit Porphyry Copper Operation.” 2003. USGS Numbered Series. 5/3/2016.

Swayze et. al. “Using Imaging Spectroscopy To Map Acidic Mine Waste.” Environmental Science & Technology. Issue 34, 2000. Pages: 47-54. 5/3/2016.

Velleux et. al. “Simulation of Metals Transport and Toxicity at a Mine-Impacted Watershed: California Gulch, Colorado.” Environmental Science & Technology. Issue 40, 2000. Pages: 6996-7004. 5/3/2016.