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# Quantifying Potential Hazard of Lienhart & Primrose Gold Mine Waste Spill, Chaffee County, CO

## Overview

In August of 2015, toxic wastewater from Gold King Mine near Silverton, Colorado spilled into a nearby river. 3 million gallons of mine waste polluted the water turning the river yellow and affecting areas in Colorado, New Mexico, and Utah. There were high concentrations of toxins such as Cadmium, Lead, and Arsenic. The unsafe levels of dangerous elements in water that many along this river use for daily life make the spill an immediate issue for local residents. The long term effects of the spill are still unclear.

I will model a scenario that analyzes the effects of a wastewater spill similar to the Gold King Mine waste spill in August of 2015. This scenario will be focused on the Lienhart & Primrose Mine near the prominent Arkansas River in Colorado. This mine is upstream from many Colorado urban areas including Buena Vista, Salida, Cañon City, Florence, and Pueblo. I will use assumptions and estimations about volume, water flow, and concentration to determine if any of the aforementioned urban areas would be in danger and how quickly they would be in danger if a similar spill could be to a river that runs through highly populated areas.

Lienhart & Primrose Mine is the mine of interest for two reasons. First, it is located upstream of the Arkansas River, and it is perfectly situated to see how concentrations affect urban areas at different distances downstream. And secondly, I wanted to pick a mine that was similar to the Gold King Mine. One assumption being made in this model is that similar mines producing similar commodities also produce the same waste material. Gold and silver are the main commodities of Gold King Mine, and it is also an underground mine. Therefore I chose to create this model with this mine that has these same properties. In this case I chose Lienhart & Primrose, a gold and silver producing, underground mine.

The results obtained in this hypothetical scenario will focus on the estimated concentrations of Copper in the river. The results will then be compared to the EPA standards for these concentrations. In this sense, the results can be quantified.

However, it is important to keep in mind that some numbers used are being estimated and are not exact. Also, this scenario is a model, so it is not precisely how the real system would function, but it is similar.

## **Data Collection**

Although the area of interest is located in Colorado, US data was more accessible, so I started mainly with large area data files before focusing on the area of interest. Specific steps taken to achieve this result will be covered in the "Procedure" section. Layers needed for this project were US states, US urban centers, US rivers, Colorado hydrography, and Colorado permitted mines. The sites to download that information were found below along with their original file names.

*US States*
Original layer name: cb_2014_us_state_500k.shp
https://www.census.gov/geo/maps-data/data/tiger-cart-boundary.html

*US Urban Centers*
Original layer name: cb_2012_us_uac10_500k.shp
https://www.census.gov/geo/maps-data/data/tiger-cart-boundary.html

*US Rivers*
Original layer name: US_Major_Rivers.shp
http://www.arcgis.com/home/item.html?id=290e4ab8a07f4d2c8392848d011add32

*Colorado hydrography*
Original layer name: NHDFlowline
ftp://rockyftp.cr.usgs.gov/vdelivery/Datasets/Staged/Hydro/
(accessed through http://nhd.usgs.gov/ )

*Colorado permitted mines*
Original layer name: All_Permit.shp
http://www.mining.state.co.us/Reports/Pages/GISData.aspx

All files were projected to the same coordinate system GCS NAD83. It was the original coordinate system of the US states layer, and therefore all layers were projected to match the US states layer.

To model a situation similar to the Gold King Mine spill I needed to access information and data from the spill. The following links provide data about concentration measurements from the mine only days after the spill.
http://www2.epa.gov/goldkingmine/gold-king-mine-data-august-12-2015
http://water.epa.gov/drink/contaminants/index.cfm

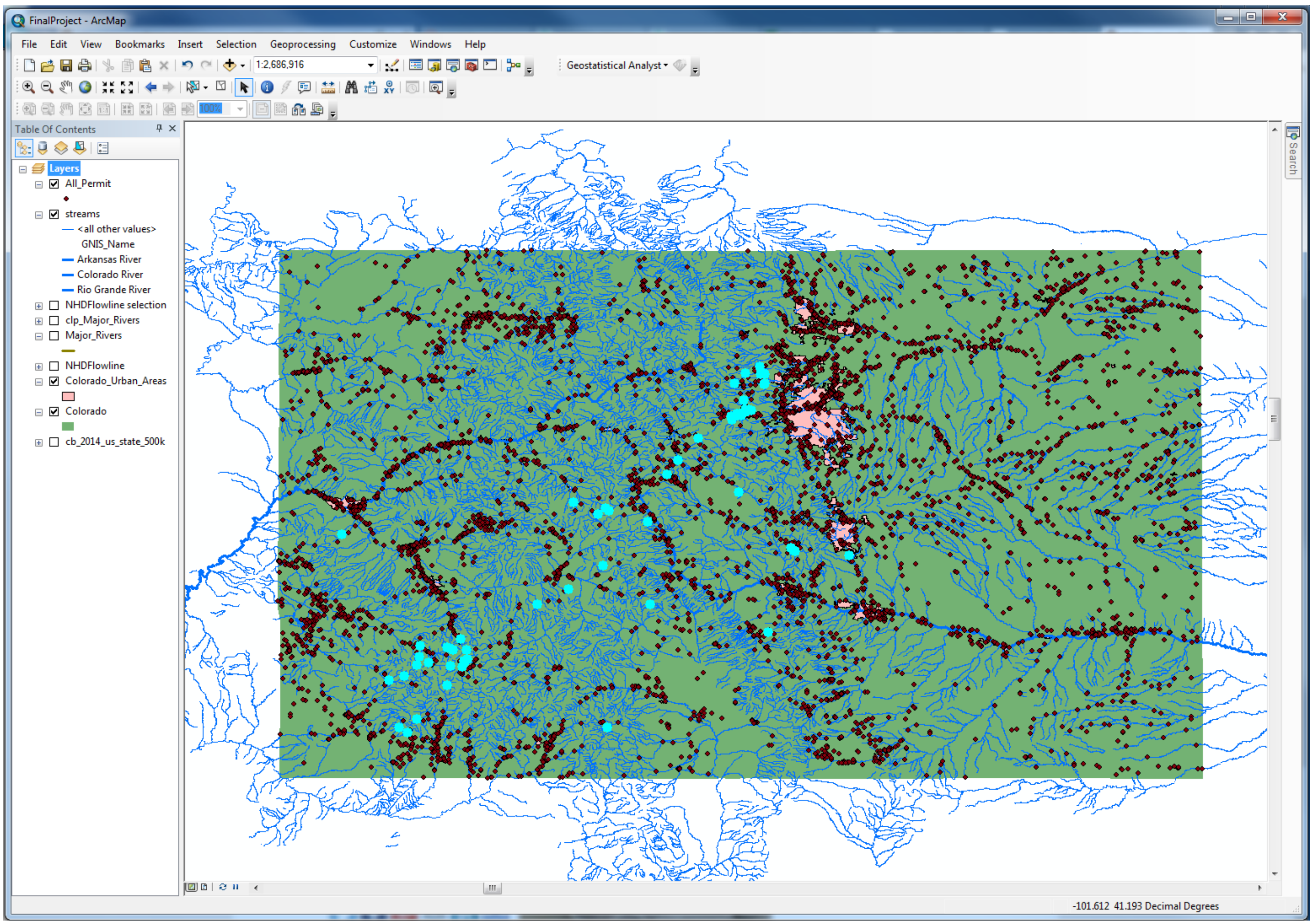
Information from Wikipedia was also obtained for other information about the Gold King mine spill. The spill rate was 610 gallons/minute and it spilled 3 million gallons of wastewater. These numbers will be used to model the scenario of a similar hypothetical spill at Lienhart & Primrose Mine.

I also found population data for my urban center areas, which I added to the layer. This information was found at http://www.city-data.com/city/Florence-Colorado.html except for Pueblo population information, which was found on Wikipedia, which includes the larger Pueblo urban area. In addition, I used http://river-depth.com/graphs/07099970 to estimate the cross sectional area of the Arkansas River.

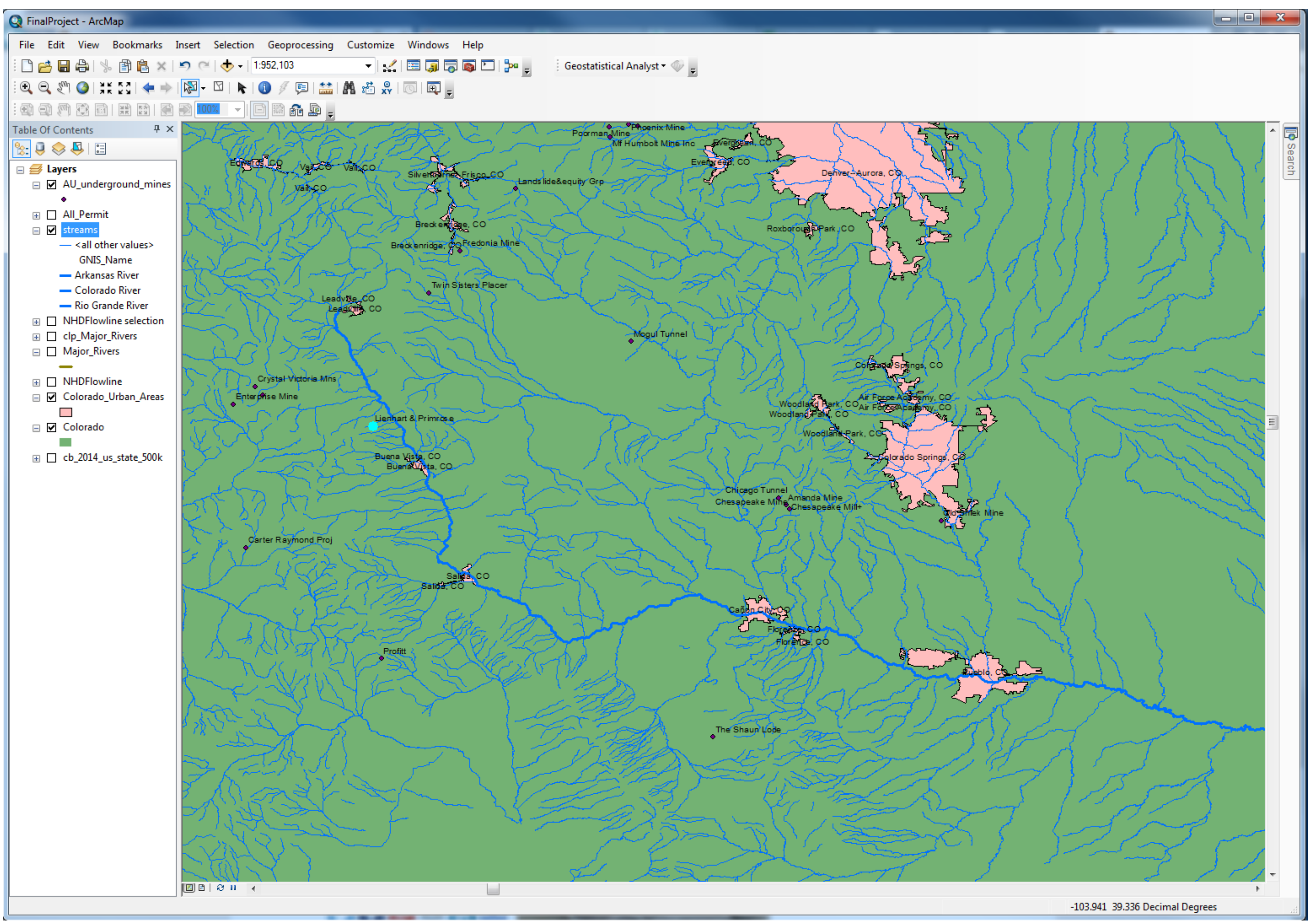
## Procedure

1) I first added the US states, US major river, and US urban center layer files to the map.
2) In the US States layer file, I selected Colorado manually and created a new "Colorado" file.
3) Similarly, I created a new "Colorado_urban_centers" file from the US urban center drive as well. For this file however, I used select by location and created a file that contained on urban centers within my recently created Colorado file.
4) Once again I took the US major river file and projected it using the project tool to GCS NAD83.
5) I then used the clipping too with the newly projected US major river file as the input feature and the Colorado file as the clipping feature to create a new file titled "clp_major_rivers".

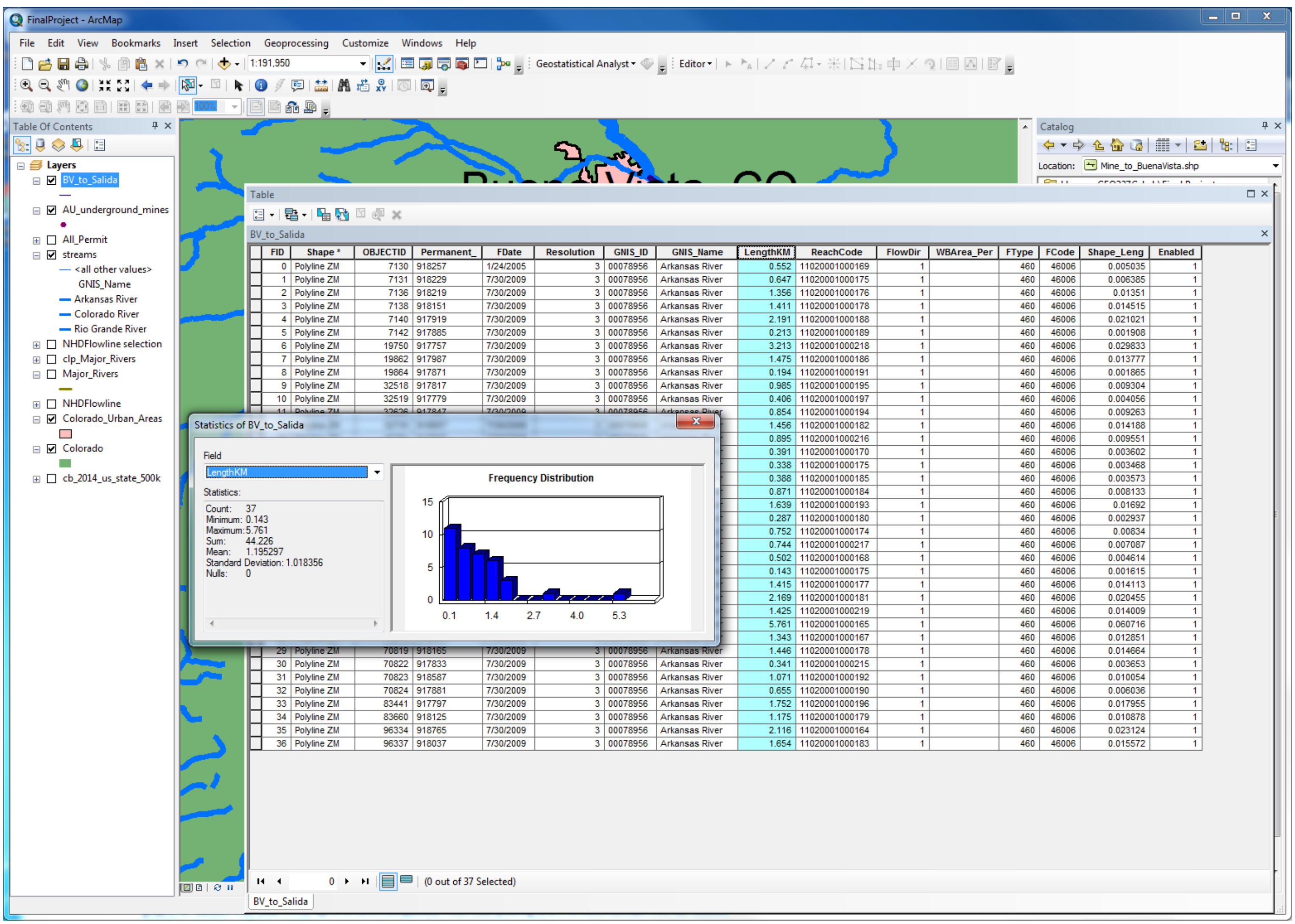
6) I added "NHDFlowline"—the Colorado hydrography layer—to the map. I created a new selection using "select by attribute" from NHDFlowline where "GNIS IS NOT NULL" and saved the file as "streams.shp".
7) I added "All_Permit" –the Colorado permitted mine layer—to the map. Using select by attributes and selecting from the All_Permit layer, I found all mines with the main commodity of gold (SQL is "commodity1" = 'Gold') and the second main commodity of silver (SQL is "commodity2" = 'Silver') and underground type of mine (SQL is "minetypede"= 'Underground'.) I did this one at a time using the "add to current selection" option. Here is what my progress looks like to this point.



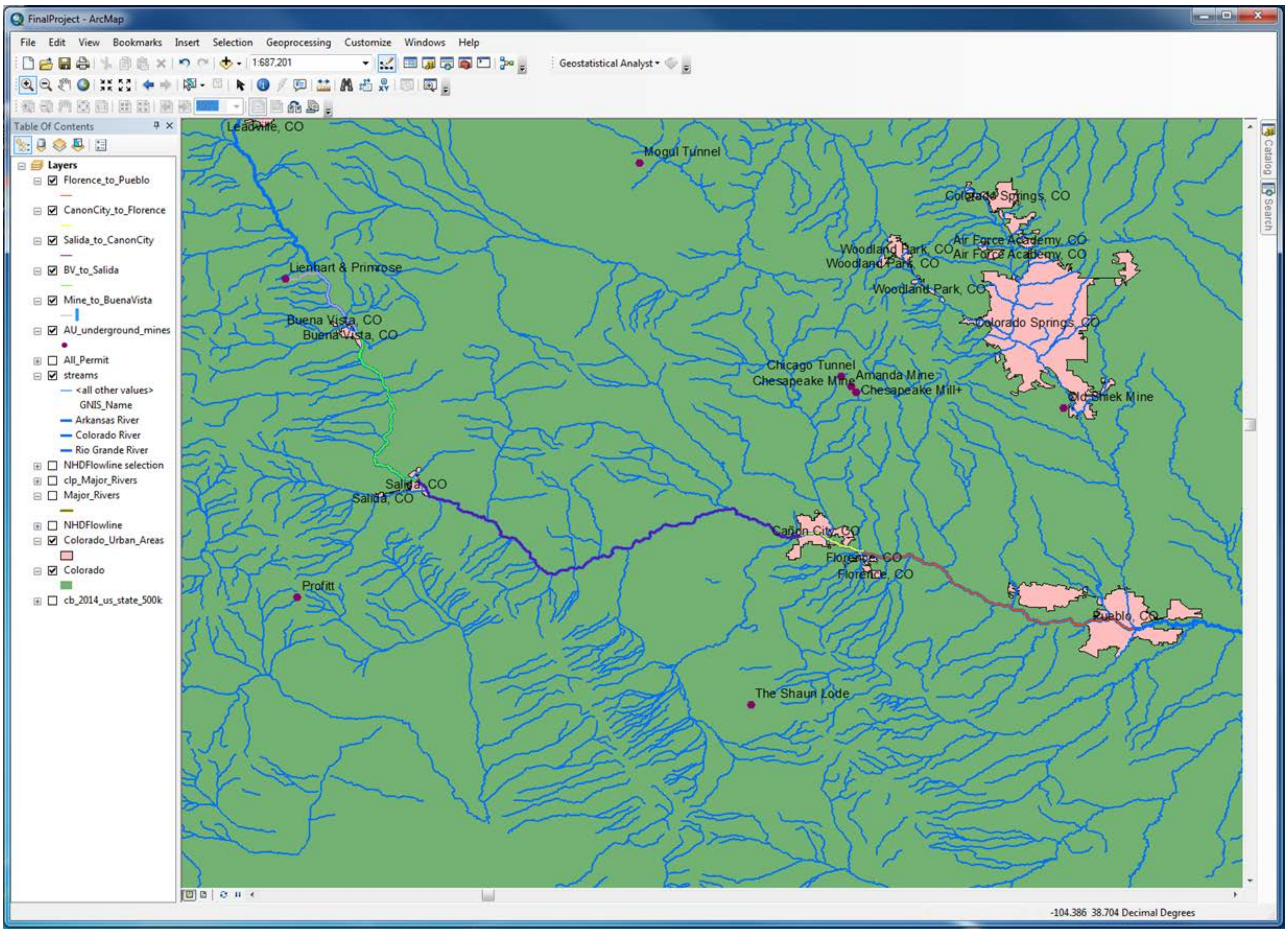
8) The selection was small, so I went through these options one by one to find a suitable model mine spill and settled on this Lienhart & Primrose Mine as my area of interest for the reason mentioned in the previous "Overview" section.
9) I wanted to add population data to my urban area attribute table to have it stored for convenience. The populations were as followed: Pueblo—160,545; Buena Vista—2,736; Salida—5,409. Cañon City—16,337; Florence—3,847. To store this information in the attribute table, I created a new field called "population". I then turned on the editor toolbar and clicked "start editing". From there, I typed in the populations for the corresponding urban areas and saved my edits. After several minor changes to labeling and symbology, this is what the project looks like.



10) I made the streams layer as the only selectable layer. The data imported has the stream lines broken into short segments. I manually selected segments that stretched from the Lienhart & Primrose Mine along the Frenchman Creek tributary that funnels into the Arkansas River and continued selecting segments up to the center of Buena Vista. I then opened the attribute table, right clicked on 'LengthKM' attribute and selected statistics. This displays the sum, which essentially gives the length of water (in kilometers) from the site of the mine waste spill to Buena Vista (21.534 km). I then saved the selection as it's own file.

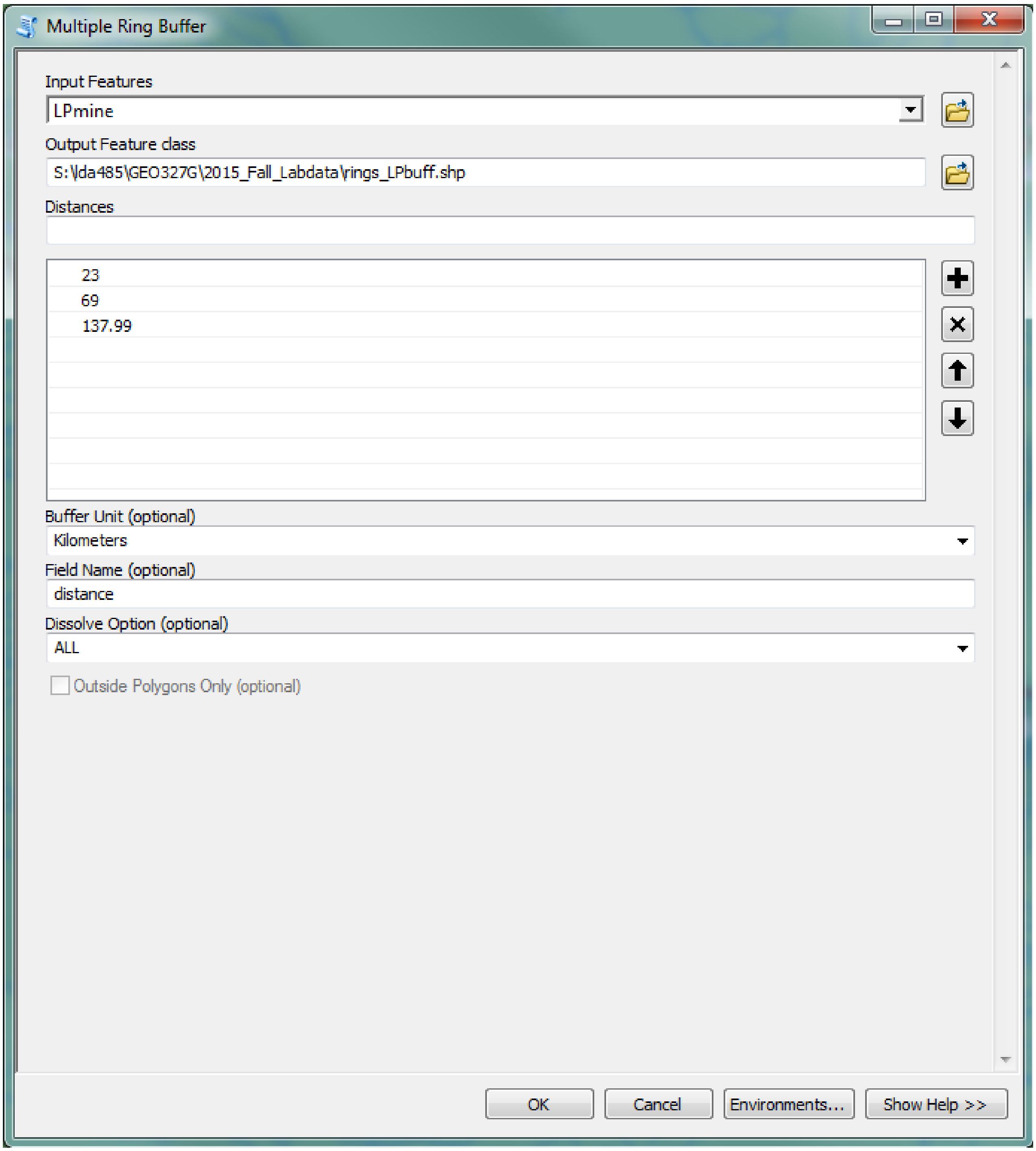


11) I repeated this process of selecting segments, finding its length, and creating a layer for each length between urban areas. In total I have the length from the Mine to Buena Vista (21.534 km), Buena Vista to Salida (44.226 km), Salida to Cañon City (91.116 km), Cañon City to Florence (12.132 km), and Florence to Pueblo (61.439 km). The distance from any urban area of interest to the mine is simply the sum of the distances of each of the segment files from the mine to the urban area of interest. In the following graphic, the five created line segment files are differnet colors to distinguish one from another.



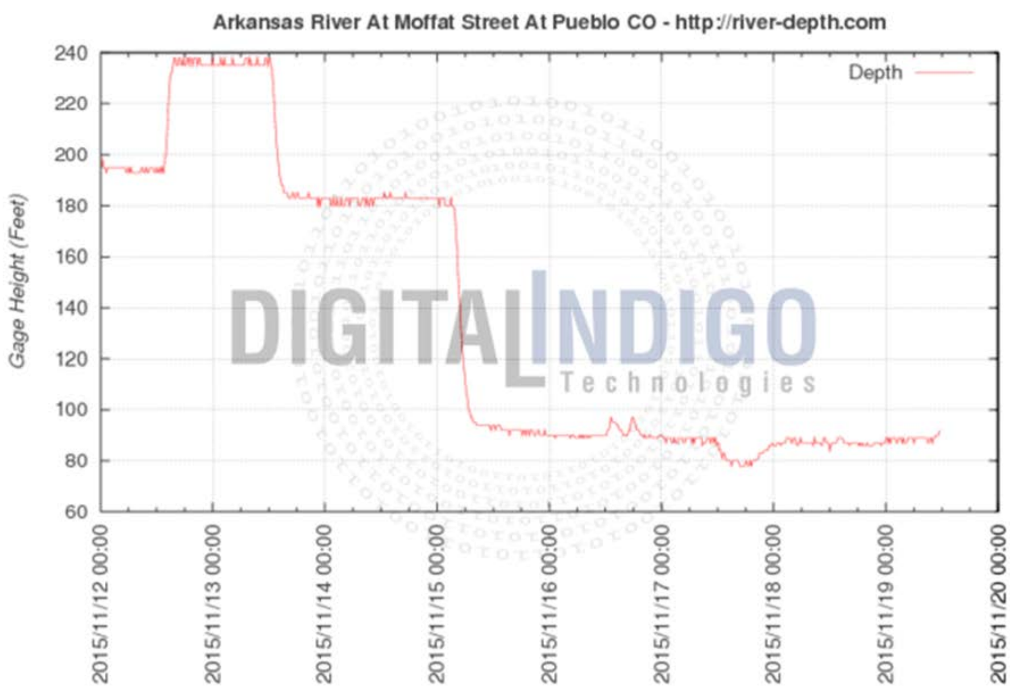
12) After a series of calculations (covered in more detail below), I needed to add a multiple ring buffer to display where high hazard, moderate hazard, and low hazard will be. I first made a new layer file that contained just the Lienhart & Primrose Mine from the AU_underground_mines.shp. I did so by just a manual selection and named the new layer "LPmine"

13) To make the multiple ring buffer, I used the Multiple Ring Buffer tool. The fields were filled like so:



## Modeling

Now that the distances between the Lienhart & Primrose Mine and each urban area are known, I will model the affect that copper would have on each urban area. A few assumptions and estimations must be made in this model. As mentioned in the overview section earlier, I am assuming that similar mines have similar wastes and therefore could have similar spills and chemicals. I am making reasonable estimates on the depth, width, and flow rate of the river.




I used data from an area of the Arkansas River along where we are looking at. It appears that the depth can fluctuate rather significantly, so I chose a rough average of 160 feet. The width of a river also can change very drastically for the same river. Therefore for simplicity we will also say that the average width of the Arkansas River is 100 feet. This is a plausible estimate for an upstream portion of a major US river.

Another assumption that must be made is that when these toxins enter the river, they are not leaving the river into nearby soils or reacting with other chemicals in the river. In addition, the model used will be a plug flow reactor (PFR) model to simply calculations. Essentially I am modeling a situation in which the Cu does not mix axially, it only mixes is the radial direction of the river, and will flow like a single unit through the river. In addition assuming that when the toxic spill comes into contact with the river it is instantaneously, completely mixed.

Very recently after the Gold King Mine spill, initial concentrations measured in the water downstream and nearby the mine were 3260 µg/L for Copper.  Copper is a toxin that, in excess, can have significant negative effects on humans. Short-term exposure can cause gastrointestinal distress while long-term exposure can cause liver or kidney damage. In addition, copper is though to be related to several different types of cancer. The EPA has set the standard to be 1.3 mg/L. Below this level copper is safe for consumption. I will now calucalte whether a spill into the Arkansas River from the Lienhart & Primrose Mine creates a dangerous concentration of copper for the urban areas downstream.

## Calculations

Our initial values mention above that I will use will be:

| | |
|---|---|
| Spill Rate | 610 gal/day |
| River Flow Rate | 56.6 $m^3/s$ |
| Total Spill | 3 million gallons |
| Initial Concentration of Cu | 3260 µg/L |
| River Depth | 160ft |
| River Width | 100 ft |

First I need to convert these values into units that are easier to work with:

Spill Rate: 610 gallons/day to liters/day is 3,323,280 L/day

River Flow Rate: 56.6$m^3$/s to cubic meters/day is 4,890,240 $m^3$/day

Total Spill: 3 million gallons to liters is 11.35 million liters

Initial Concentration of Cu: 3260 µg/L to mg/L is 3.260 mg/L

River Depth: 160ft to meters is 48.8 meters

River Width: 100ft to meters is 30.5 meters

Ultimately I want to calculate the concentration of copper in the river after the spill has run to completion and the time after the initial spill that the concentration will hit each urban area. First I will need to calculate the total time it takes for the waste to spill. Simply dividing the total liters spilled by the spill rate will give us the answer:

*1.135e7 Liters ÷ 3,323,280 Liters/day = 3.415 days to spill*

I can multiple the river flow rate and the days to spill to calculate the total volume of water that has mixed with the spill:

*4,890,240 $m^3$/day × 3.416 days = 1.6705e7 $m^3$*

I will then multiply the initial concentration of Cu and the total volume of the spill to obtain the total mass of the spill. I then can take that answer and divide it by the total volume of water that has mixed with the spill to calculate the concentration:

*3.260 mg/L ×11.35e6 L = 37,001,000 mg of Cu*

*37,001,000 mg of Cu ÷ 1.6705e7 $m^3$ = 2.21 mg/L of Cu*

I can calculate the volume of the river using the width and depth of the river along with the GIS measured length. From that I can use the flow rate to determine at what length down the river did the spill travel until it spilled to completion.

*48.8m * 30.5m * X km = 1.6705e7 $m^3$*

*X = 11.224 km distance the spill was downstream when the spill stopped*

Because the distance to Buena Vista is 21.534 kilometers, the spill will have run to completion before it affects the first urban area of interest. However, because the river acts as a plug flow reactor, the concentration of Cu in an ideal system will stay at 2.21 mg/L and pass through the Buena Vista urban area at that concentration. In addition, because the spill rate of the mine and the flow rate of the river are both constant and continuous, that concentration will flow through Buena Vista for the length of time of the spill—3.146 days. To find the time that it takes the spill to reach Buena Vista I will solve for an unknown time. To do so, I find the volume between the Lienhart & Primrose mine and Buena Vista by multiplying the distance by the cross sectional area, and then dividing the flow rate of the river to get the days.

*21.534 km * 1000 * 48.8m * 30.5m ÷ 4,890,240 $m^3$/day = 6.55 days*

I will follow the same procedure to find the time it takes for the toxin in this plug flow reactor model to get to each city. The cross sectional area will be the same for each, but the distance to each urban area, determined by GIS techniques will be different, and thus will produce different times.

*Time until spill and concentration of 2.21 mg/L of Cu reaches each urban area:*

*Buena Vista = 6.55 days*

*Salida = 20.01*

*Canon City =47.75*

*Florence = 51.44*

*Pueblo = 70.14*

To create the multiple ring buffers, I will create three rings to represent a week to prepare for the spill, 3 weeks to prepare for the spill and 6 weeks to prepare for the spill. To do so, the buffer rings will be whatever distance the spill travels in 7 days, 21 days and 42 days. To find those distances I used the same equation as before. Rather than solving for time however, I will solve for distance.

*X km * 1000 * 48.8m * 30.5m ÷ 4,890,240 $m^3$/day = 7 days*

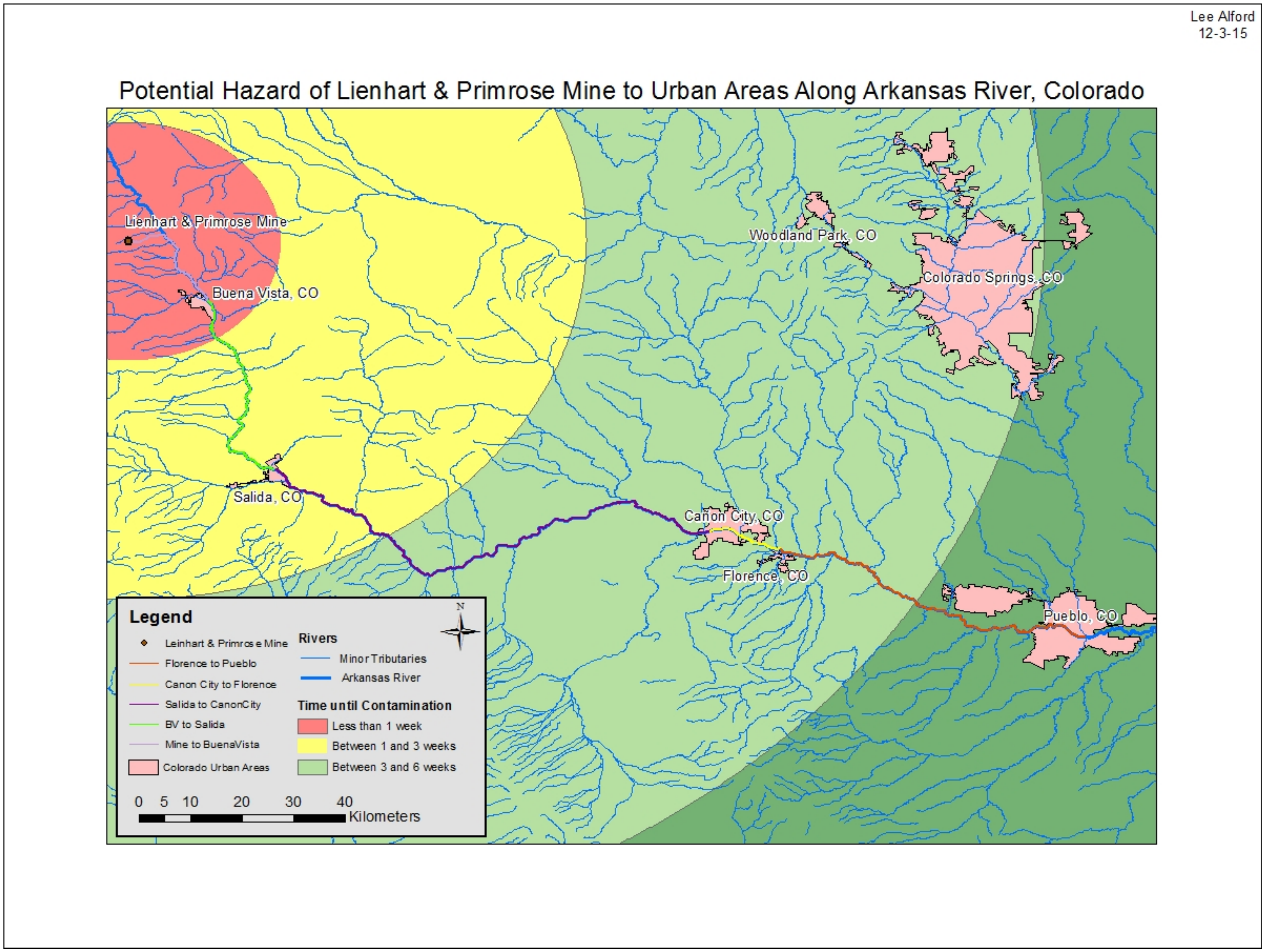
*23.00 km in 7 days or 1 week*

*69.00 km in 21 days or 3 weeks*

*137.99 km in 42 days or 6 weeks*

## Data Presentation

The final map indicates the hazard levels for areas in proximity to the mine:




## Discussion

Not surprisingly, the further the urban area is in proximity to the mine, the longer it takes for the toxin to reach the city. The EPA standard for Cu concentrations in water is 1.6 mg/L. A higher concentration as a consequence of the spill means that Buena Vista, which is only 6.55 days away from the spill, is in the most trouble. Nearly 3,000 people would be in danger less than a week after the accident, and in many cases that may not be enough time to alert the city, come up with alternative water options, and provide for a city of 3,000 for the 3 days that the water would be contaminated. Therefore I have used 1 week as the first buffer for the spill representing high hazard. 3 weeks is used as the second buffer representing an area of moderate hazard. 3 weeks may or may not be enough time for things to dilute to a safe level or for cities to control the situation. Salida is the only urban area that is in moderate danger. I think it is reasonable to assume that 6 weeks is more than enough time for cities to take action, control the waste, and protect water supplies—citizens would not need to worry. Cañon City and Florence are both in the low danger buffer ring. Pueblo, an urban area of over 150,000, is safely outside of all three hazard areas. Pueblo would have more than 6 weeks to prepare for a major spill at the Lienhart & Primrose Mine, and likely would be completely unaffected by this catastrophe. Because the river is amalgamating, the multiple ring buffer overestimates which areas are in danger. This is okay because that may cause certain urban areas to take extra precaution rather than not enough precaution.

Cañon City, Florence, and Pueblo will experience the contamination much later than Buena Vista. It is reasonable to think that those cities would be able to come up with solutions to this environmental emergency before the spill arrived there. Salida is certainly in more danger than Cañon City, Florence, and Pueblo, but not more than Buena Vista. This project models a simple system; one thing not taken into account are tributaries flowing into the Arkansas River and effectively diluting the concentration of Cu. Further analysis could determine more precisely which cities would be in danger and which cities will have the toxins diluted enough by the time the toxins reach them.