Climbable Sections of Canyon Wall

Big Thompson Canyon, Colorado

Benjamin Kastner

GEO-261 and GEO-361 at Calvin College

Spring 2019

Introduction

Flash floods have occurred in Big Thompson canyon in 1976 and 2013. The 1976 flood killed 144 people (Colorado Geological Survey 2013). The 2013 flood killed 9 people across Colorado (Colorado Geological Survey 2013). Both floods washed out sections of the road (US 34) through the canyon. The people who attempted to drive away were less likely to survive than those who moved to higher ground (Gruntfest as cited in Jarrett and Costa). Remaining in the floodplain was also unwise (Jarrett and Costa 2006). In 1976, the river rose to heights of 20 feet where it is usually only a few feet (Jarrett and Costa 2006). I've had a difficult time finding the height of the 2013 flood – a preliminary report from the Western Water Assessment suggests the peak at the canyon mouth was at least 8.2 feet (Lukas 2013)

Problem

While driving through the canyon, drivers see a sign telling them to "climb to safety" in case a flash flood happens. My mom wondered how she was expected to climb up a rock wall that might be wet and, depending on the time of day, dark. This is a concern because if the climb looks too difficult, drivers might linger in their cars instead of immediately climbing to safety. Some places of the canyon will be easier to climb than others due to the slope of the wall. Knowing where the relatively easy places are will assist the placement of signs pointing visitors to escape routes and show which stretches of the canyon lack reasonably easy escape routes. Artificial escape routes (e.g. ladders or stairways) could be installed at strategic points to increase survivability in case of a flash flood.

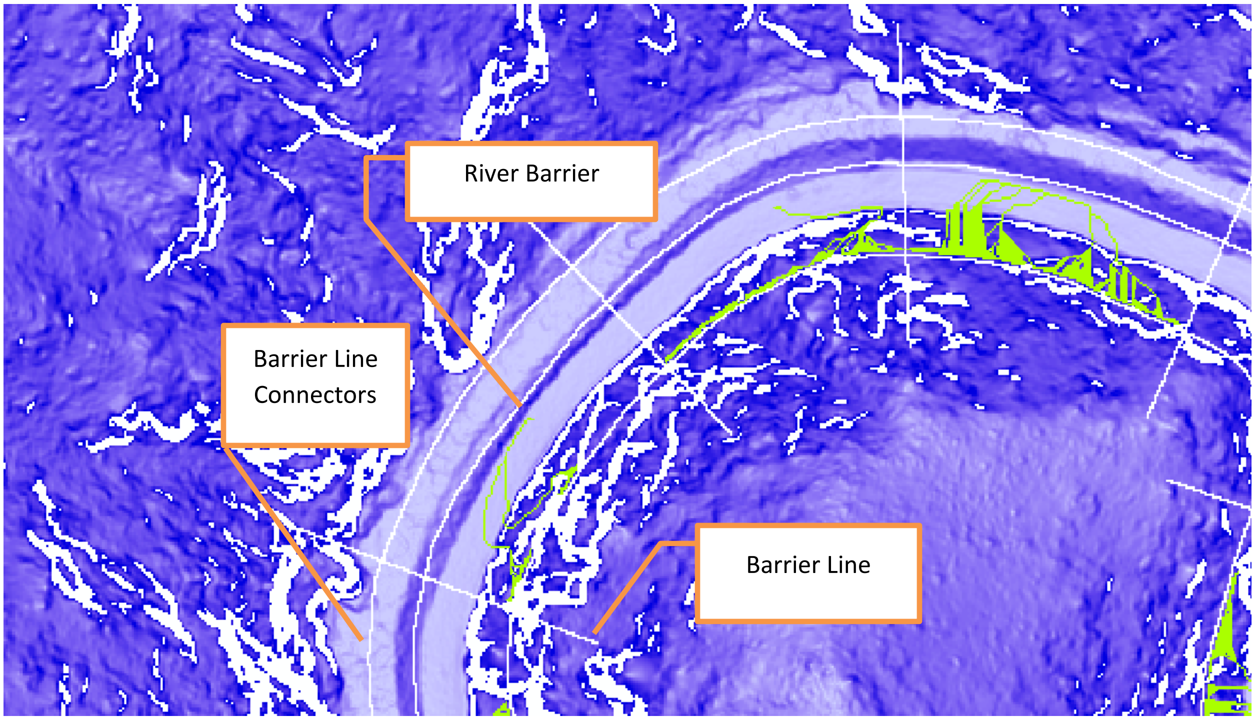
Objectives

1. Determine which sections of the road are near (within 1/16 of a mile, or 330 ft) of a climbable route up the wall. This is a little more than the length of a football field. Climbable is defined as having a slope not greater than 60 degrees.
2. Present these sections using a printable map (PDF file)
3. Present these sections using an ArcGIS Online web app
4. Visualize the routes in 3d (ArcScene)
5. Present the 3d routes using ArcGIS Online

Process

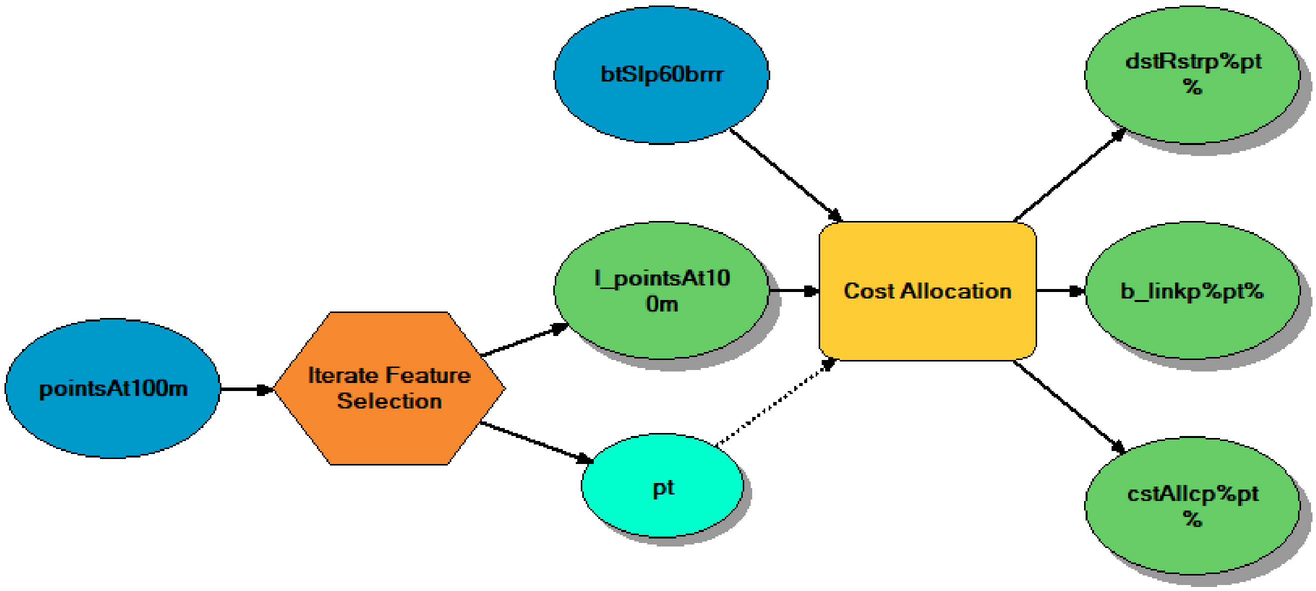
1. The state of Colorado has DEM data with 0.75 m resolution that was taken after the 2013 event. The DEM comes in separate chunks, so I merged them into one large DEM.
2. Imagery from 2011 was obtained from NAIP via USGS Earth Explorer.

3. I drew a vector line on top of the road, following the centerline as best as I could – some areas of the road were in shadow.
4. I computed slope and aspect rasters.
5. I deleted all cells with slope greater than 60 degrees from the slope raster using Spatial Analyst Tools > Map Algebra > Raster Calculator with the formula SetNull(bt_slope, bt_slope, "Value" > 60), where bt_slope is the unedited slope raster.
6. I created points using the Create Points tool from the Editor toolbar. Points were placed at intervals of 100 meters on the road centerline. I chose 100 meters because it is roughly 1/16 of a mile. I also chose new location for points because they were on a bridge (I decided not to have paths cross bridges, as discussed below). For the points that I moved or added (if I wanted points on both sides of a bridge instead of one point on a bridge), I positioned them based on my own guess of whether there were better paths on one side of the bridge or another.
7. I created a line following the edge of the road that is closest to the river (I'll refer to it as the river barrier). I decided not to have any paths cross bridges because there is a chance the bridge might collapse. The psychological factor of crossing a bridge with a flash flood underneath could cause someone to avoid crossing the bridge even if it leads to an escape route. I added extensions to the river barrier line near bridges to keep the Cost Path tool from going over the river. I was not completely successful in this because I missed a couple areas. I placed a section of the river barrier feature at the northernmost point of the DEM to keep a later map algebra operation from leaving out the northern part of the DEM.
8. I computed destination lines parallel to the road but 20 meters horizontally from it. The lines were adjusted to be either 20m from the road or approximately 30 feet above the road. The default is 20 meters from the road; the line was adjusted to be approximately 30 feet above the road if it looked like 20 meters from the road would not get it high enough above the road. A more methodical, programmatic way of doing this would be better.
9. I wanted to keep cost path analysis confined to a section of the road. I didn't, for example, want a path that went a mile up the road, up the wall, and then back along the wall. To accomplish this, I decided to create barriers of no data in the raster surrounding each point. To do this, I added the field IDCRTRT (shorthand for ID Create Route) to the road centerline. I ran Linear Referencing Tools > Create Routes, selected IDCRTRT as Route Identifier Field and called the output *routes*. A post on GIS StackExchange was helpful in directing me toward linear referencing (Fairhurst 2018) and I eventually found an ESRI help article describing the steps to accomplish what I wanted to do.
10. I created tables in Microsoft Excel, imported them to ArcGIS and called them routeOffsetsPos and routeOffsetsNeg. I used Linear Referencing Tools > Make Route Event Layer to make two layers, routeOffsetsNegEvents and routeOffsetsPosEvents. I then merged the two event layers into routeOffsetsMerge. This created lines of points at the specified offset. NOTE: I've included the Excel file below. I may have changed the offset value to 20 after importing the tables into ArcMap.
11. To create lines between each pair of points, I ran Data Management Tools > Features > Points To Line with input of routeOffsetsMerge and specified LOCATION as the Line Field. I called the output barrierLines. I had to extend some barrier lines so that they crossed the destination line in the places where I had modified the destination line.

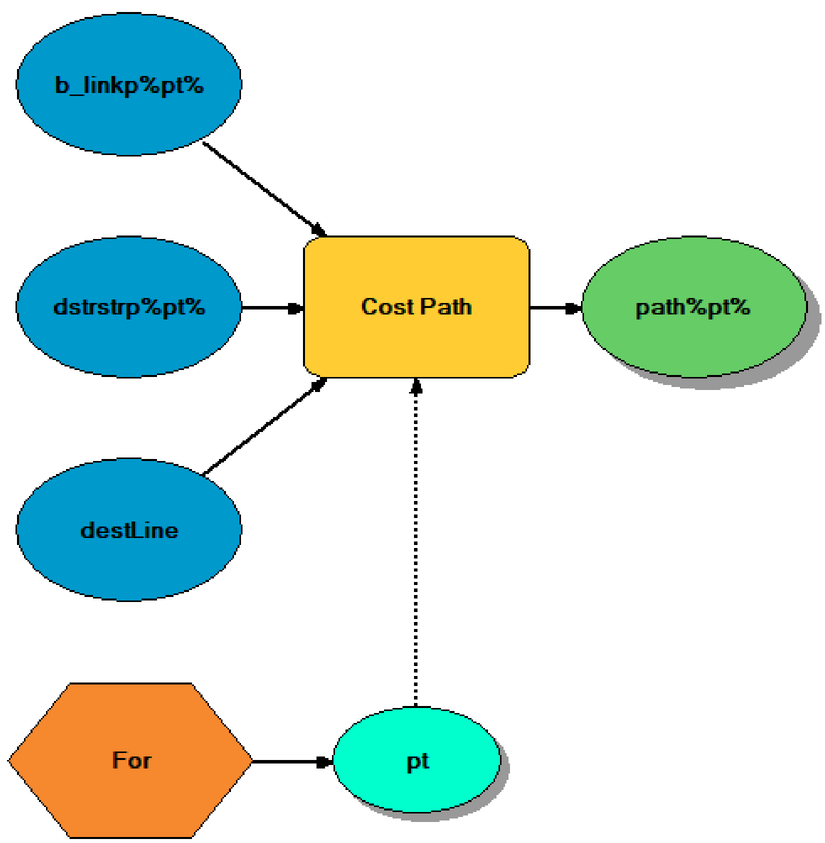
12. 

13. I created another pair of lines just outside the destination lines and named them barrierLineConnectors. I then merged barrierLines, barrierLine connectors, and river barrier and converted the resulting feature class to a raster with cell size of 0.75.
14. To create the barriers in the slope raster, I ran Spatial Analyst Tools > Map Algebra > Raster Calculator with formula SetNull(~IsNull("brrrLnsRstr"),"bt_slope_60"), where brrrLnsRstr is the barrier lines and bt_slope_60 is the slope raster. A GeoNet forum post provided the formula (brannjkb 2013). I had to move point #1 because it was right on the barrier line, which made cost analysis on that point impossible.
15. I ran the Spatial Analyst Tools > Distance > Cost Allocation and Cost Path tools. Because I wanted to run each tool with each individual point as input, I used the following models to automate the process. Cost Allocations took approximately 3 hours and Cost Paths took approximately 1 hour.

16. Cost Allocation model:



17. Cost Path model:



18. Each set of paths was generated as a separate raster. Ran Data Management Tools > Raster > Raster Dataset > Mosaic to New Raster with the input of all the paths, spatial reference NAD_1983_UTM_Zone_13N / VCS:NAVD_1988, # of bands = 1, and left the pixel type at 8 bit unsigned. Called output allPaths60.
19. NOTE: I don't think Cost Path found all the feasible routes, because there could be areas where the entire wall is climbable, but paths are only shown every so often. However, this shows that there are paths at least at those locations.

2D PDF Map

1. I ran Data Management Tools > Generalization > Eliminate on the paths. This was to remove unnecessary polygons and hopefully improve performance. Unfortunately, I'm not sure whether I check or uncheck the box to tell ArcMap which elimination method to use (longest edge or biggest area).
2. I used Cartography Tools > Data Driven Pages > Strip Map Index Features with the destination lines as input. I chose to use page unit and scale, set the map scale to 2500, and named the output.
3. I used the Data Driven pages wizard to set rotation to Angle, page number to Page Number, and Layer to the strip map index feature. I made sure the current map scale was set to 2500 and then went to the Extent Tab and chose Center and Maintain Current Scale.
4. I exported with all pages as a single PDF.
5. NOTE: I chose to show all the routes because the goal is to get off the road as fast as possible. All the routes shown are feasible, so you should use the one closest to you. I decided this was worth the tradeoff of a busier map.

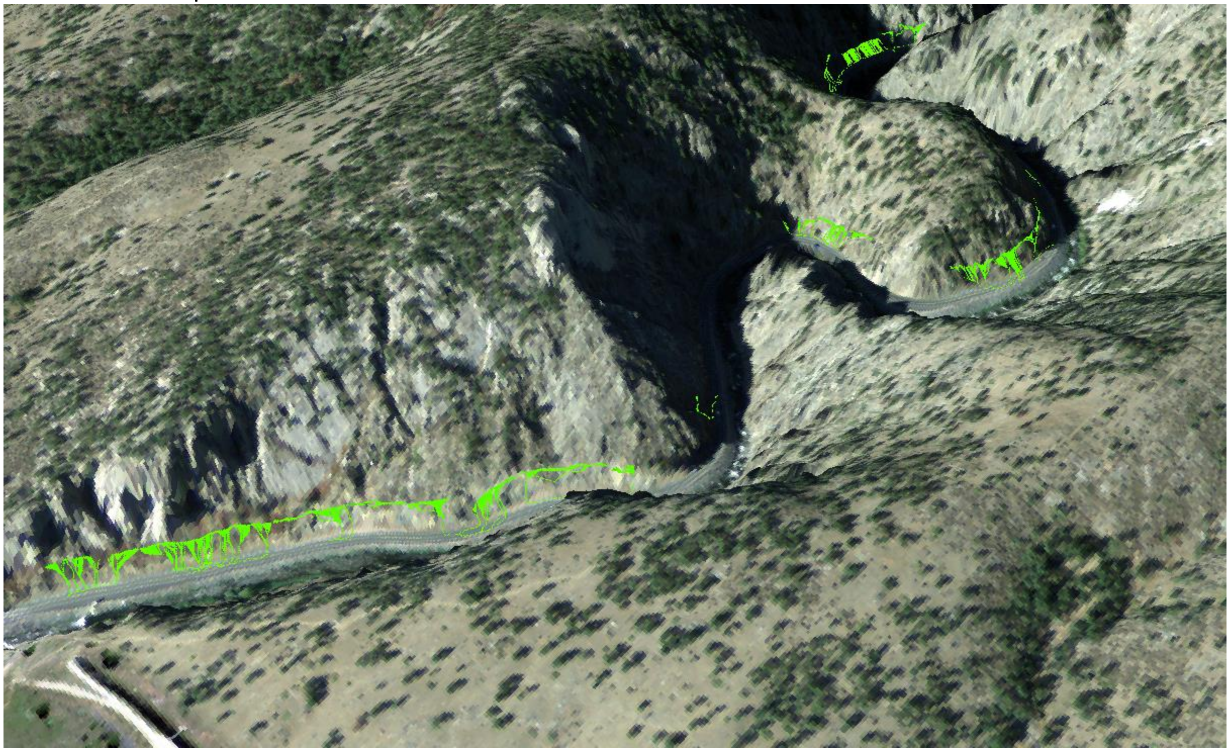
2D Web App

1. I zipped the mile posts shapefile and the paths shapefile and emailed them to Professor VanHorn to be put on ArcGIS server (they were too big to import directly into ArcGIS Online with a free subscription).
2. I created a web map with the road centerline, paths, and mileposts.
3. I created a web app from the web map using the basic view template.

3D Model

1. I imported the DEM into ArcScene along with the imagery and the paths. I increased raster resolution on one imagery file to get it to display (raster also doesn't display in that area).
2. I set the base height of the imagery and lines to the DEM.
3. I encountered difficulty positioning the paths relative to the imagery. I tried various offsets for the line, but it always seemed like some portions of the line ended up below the raster and some above it. A compromise was a conversion factor of 1.0015. This is less than perfect because I doubt all paths are shown.

Here is an example of what the scene looks like:



3D Animation

1. I created a copy of the road centerline for the camera to follow. I then used Cartography Tools > Generalization > Smooth Line to smooth the line. I chose a smoothing tolerance of 1m.
2. I Used 3D Analyst Tools > Functional Surface > Interpolate Shape to convert the camera line to a 3D line. A USGS document was what led me to convert the line to 3D (United States Geological Survey n.d.)
3. I then selected the camera line and chose Animation > Create Flyby from Path. I set the simplification factor to the minimum. Under Orientation, I set an absolute value for incline and roll.
4. I exported the scene to an AVI file using the Microsoft Video 1 compressor with default settings. The export failed if I attempted to export the entire scene at once, so I had to export it in chunks. I imported the chunks into iMovie on my MacBook, merged them into one file, and exported it as a .mp4 file.

3D Image Series Export

1. I changed the animation so that the view is from higher above the road. I then exported the animation as a series of sequential images, both from East to West, and from West to East. The animation doesn't always give a good view of the paths, so running it from both directions is an attempt to generate at least one good image of each spot. I set this animation to be 1000 seconds long and exported 1 image per second, for a total of 1000 images each way.

3D Web Scene

1. I removed all layers except for essential imagery and the paths. I used 3D Analyst > CityEngine > Export to 3D Web Scene to export the scene. I then uploaded the scene to ArcGIS Online and shared it publicly.

Results

Caveats

The DEM was created right after the 2013 flood event, so it will display road damage. Also, it does not consider the improvements made to the road after the flood. The imagery is from 2011, so it does not show flood damage. Some routes actually go down from the road – this is because I was unable to see the down-slope from areal imagery. The destination line would need to be moved farther away from the road to correct this.[1]

Observations

I had originally planned to show the sections of road that were more than 1/16th of a mile away from a climbable slope, but it turns out that most sections are within 1/16th of a mile of a climbable route. The main exceptions are at the East end of the canyon (see page 27 of the PDF maps).

Perhaps part of the reason for my family's perception of the canyon wall as difficult to climb is the placement of the warning sign – had the sign been placed 2 miles into the canyon near a less-intimidating wall, we would be more confident in our ability to climb out of the canyon in the event of a flash flood. Perhaps the psychological factor of the placement of warning signs needs to be considered, not just in Big Thompson Canyon, but it other potentially hazardous areas.

Deliverables

2D Web App

3D Web App

Full Animation:

Short, "trailer" animation

Sequential Images from East to West and West to East.

See benjaminkastner.com for PDF maps.

References

brannjkb. 2013. Reply. *GeoNet*. https://community.esri.com/thread/21531.
Colorado Geological Survey. 2013. "Floods." Colorado Geological Survey. June 20, 2013. http://coloradogeologicalsurvey.org/geologic-hazards/floods-2/.
Fairhurst, Richard. 2018. Reply. *GIS StackExchange*. https://gis.stackexchange.com/a/297597.

---

[1] It is worth mentioning that any depression may be filled with water in the event of a flash flood, because it might have been raining before the flood. A better choice might be to exclude any routes with a downward component.

Jarrett, Robert D., and John E. Costa. 2006. “1976 Big Thompson Flood, Colorado—Thirty Years Later.” Fact Sheet FS-2006–3095. United States Geological Survey. https://pubs.usgs.gov/fs/2006/3095/pdf/FS06-3095_508.pdf.

Lukas, Jeff. 2013. “Severe Flooding on the Colorado Front Range.” Western Water Assessment. September 25, 2013. https://wwa.colorado.edu/resources/front-range-floods/assessment.pdf.

United States Geological Survey. n.d. “Animation Circle Path from Points.” United States Geological Survey. Accessed May 9, 2019. ftp://pdsimage2.wr.usgs.gov/pub/pigpen/tutorials/Animation_Path_from_Points_ArcScene.doc.