2013 FLOODS: MAPPING HYDROLOGY AND IMPACTS IN LARIMER COUNTY, COLORADO

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Introduction

From September 11th to September 17th in 2013, the front range of Colorado experienced record rainfalls. In the intervening years, much of the focus and study of flood and damage has been in Boulder County, many parts of which experienced close to the average cumulative rainfall for the entire year in just 2 days [1]. This study seeks to us ArcGIS to take a closer look at Larimer County, which saw less intense rainfall, but experienced significant damage, much of which was outside of FEMA flood plains. In an effort to find explanatory factors for these outside damage points, the data points were examined against various other factors, both qualitatively inside of GIS, and more quantitatively using data tables extracted from GIS.

Background

On September 9th, 2013, a large low-pressure system settled over the Colorado Front Range region, pulling tropical moisture from both the Pacific Ocean and the Gulf of Mexico [2]. This resulted in heavy rains, peaking from September 11th to September 15th, and caused floods from the onset until September 18th [2]. While the intensity of the rain was heavy, it wasn't exceedingly unusual, but the duration and constancy of the put the accumulated rainfalls at 1000-year probability levels in many places throughout the state, meaning that in any given year, accumulated rainfall of this magnitude would have a probability of 0.1% [3]. However, despite the magnitude of the rainfall, the measured streamflows did not reach the same level of magnitude [6]. This is thought to be due to the prolonged nature of the storm, and the storm being generally oriented perpendicular to drainage patterns [6].

Flooding occurred over a span of nearly 200-mile north-south stretch, affecting 17 counties [4]. More than 11,000 people were evacuated, and more than 2,100 people had to be rescued by the National Guard, mostly in mountain communities [4]. Initial estimates of the cost to repair damages were at 2 billion USD, including an average of 200 USD in property damage per each of the 4 million people who lived in one of the 17 affected counties [5].

Rainfall in the Rocky Mountain region can turn destructive in ways that it can't in flatter regions, with the steep terrain carrying water at high speeds. These fast moving waters can rips homes apart, and cause greater damage than the submersion element.

In the intervening years, much of the focus in analyzing the floods has been in Boulder County, which saw the most intense rainfalls. To that end, this study set out to focus on Larimer County, which didn't see as intense of rainfall, but still experienced large amounts of damage. The initial intent of the study was to present a series of cohesive images examining the impacts, in the form of a story map, but as the data was explored, it was clear that many of the relationships between hydrology and damages weren't as one would expect, and the focus of the study shifted to exploring those ends.

Estes Park, which became the focus of much of the analysis, is home to the Rocky Mountain National Park Headquarters, a variety of summer camps, the Stanley hotel, and generally serves as a tourist destination for the region. Many of its residents live in mountainous areas, and were left isolated when roads were damaged during the flooding [2].

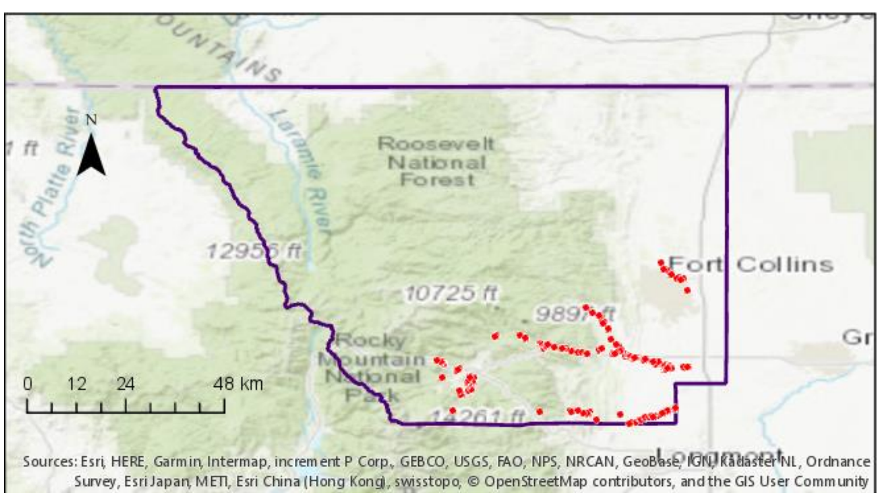
Data Gathering

The majority of the data available for this project was in the North American 1983 GCS, so all data that was not in this system was projected in that system using the Geoprocessing “Project” tool. Without an initial area of focus, doing height above nearest drainage (HAND) modeling for the entire region was not practical, so the national HAND model computed by the University of Texas at Austin Texas Advanced Computing Center was used. Elevation data was taken from the USGS. Address points and floodplain data was downloaded from Larimer County’s GIS homepage.

As this study was primarily aimed at analyzing impacts, finding data on damaged buildings was key. The most comprehensive data source available was found at through the FEMA, which collected thousands of structural damage points, 615 of which were in Larimer County [1]. FEMA also road damage points available. With both sets of points, the It is important to note that these points only represent structurally damage, and that buildings or road that were inundated but not structurally damaged were not included. FEMA also had 3 areas of the flood extents in Larimer County, based off of data measured during the event by the cities the flooding occurred in. FEMA has also gathered an extensive database of all the structures in the Estes Park region, with data such as when the house was built, its size, and whether it had a basement, but this data did not give any further insight into damage status.

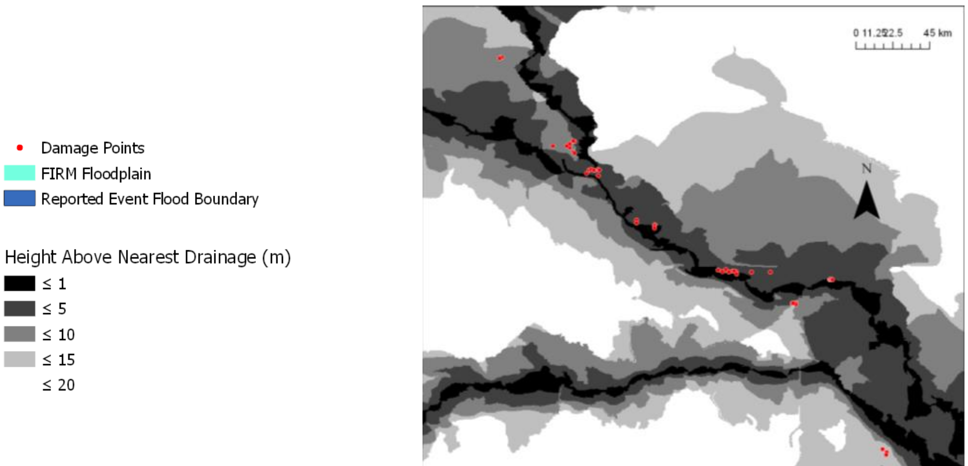
Mapping and Analysis

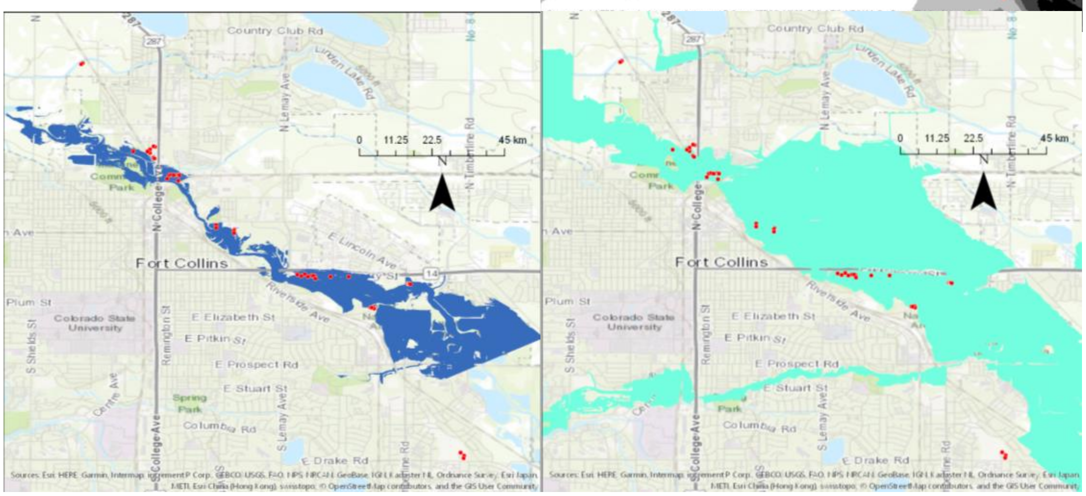
As a first step in processing, all data was limited to the extent of Larimer County, either by trimming raster data sets to the Larimer County Boundary, or by copying feature classes after using the “Select by Location” tool. An overview of the damage points shows that the major damage was confined to the southwest corner of the county, and is broadly in 4 large clusters.



Zooming into these 4 areas, the data points were compared to 3 sources: HAND modeling completed by the University of Texas at Austin Advanced Computing Center (TACC), the FIRM floodplains, and where available, the flood extent for the event measured by town jurisdictions.

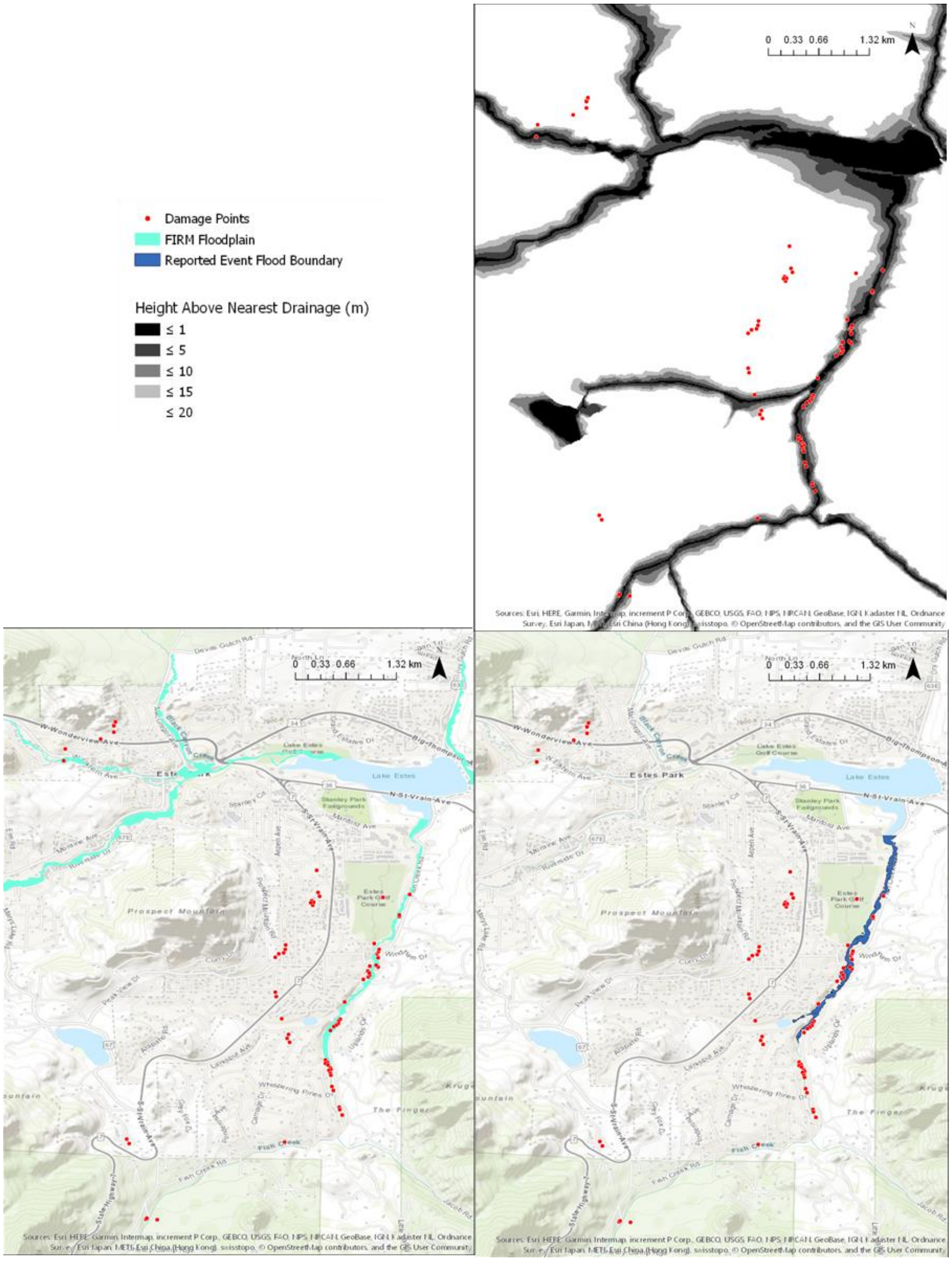
FORT COLLINS





In Fort Collins, we see the damage mostly in line with the flood extents and FIRM floodplain, but there are several points just outside and a few completely outside the reaches. These maps also illustrate that in this area, the flood extents were generally lesser than the FIRM floodplain.

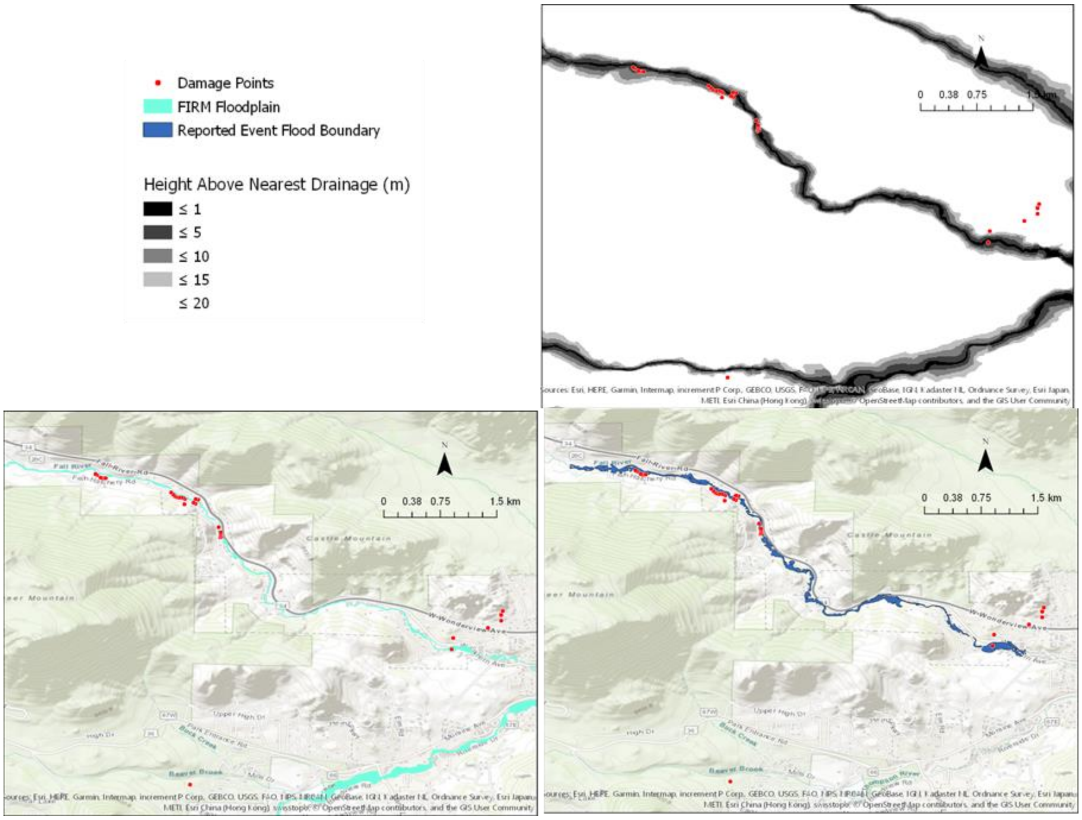
ESTES PARK – FISK CREEK



In this Estes Park Region, we see much many more damage outliers from the floodplain and flood extents, and while some seem to be explained by a lower Height Above Nearest Drainage values, there are still outliers beyond those. The flood extents reach a greater area than the

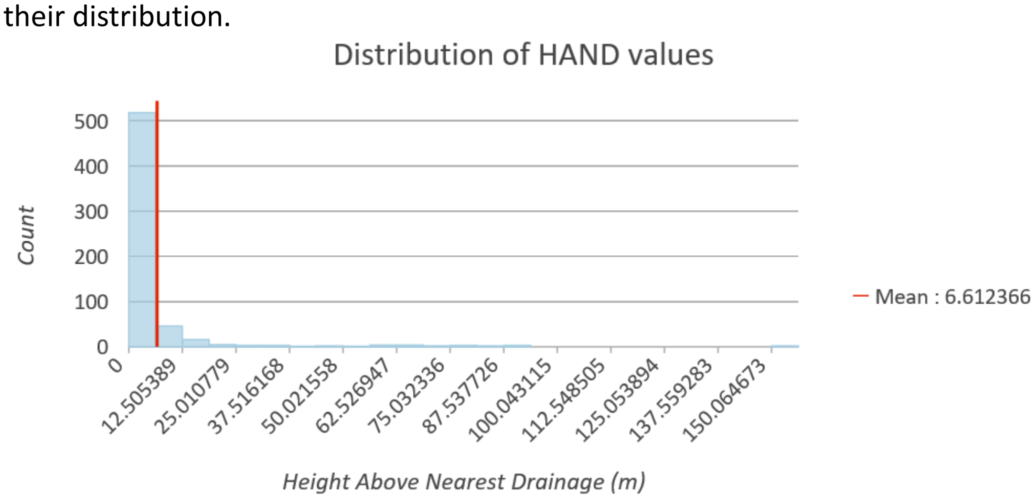
FIRM floodplain, suggesting a flaw either in the development of the floodplain, or a highly improbable flood extent.

ESTES PARK – FALL CREEK

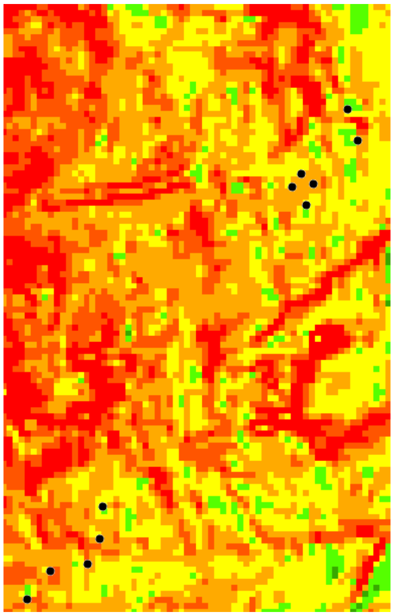


Again, we see several outlier damage points, with no clear or intuitive explanation for the flood damage, and the FIRM floodplain has a smaller footprint that the actual flood extents.

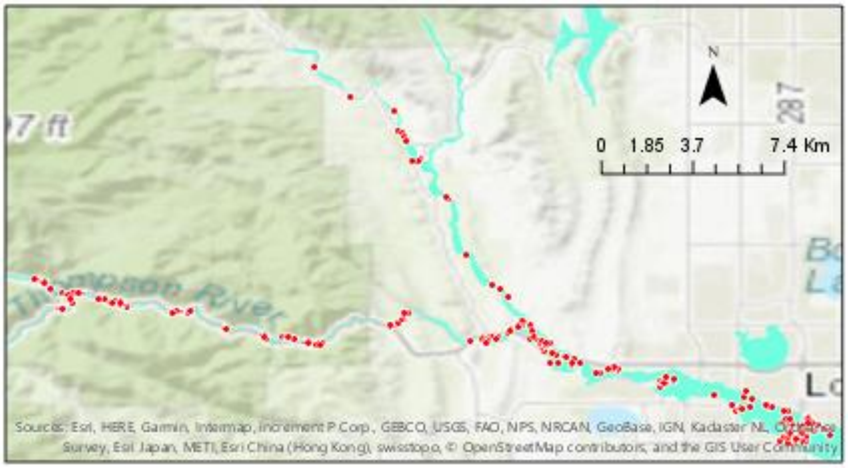
To investigate the outliers further, the HAND values were extracted for each damage point, and plotted their distribution.



While there is a high frequency of lower HAND values, There are 97 damage points, out of a total of 618, that are more than 12 meters above the nearest drainage point. While HAND and floodplain modeling are effective at predicting which houses will be submerged, it can't account for destruction caused by fast moving waters, as the rain makes its way towards its drainage point. To examine this further, a slope raster was calculated from the USGS DEM, and the outlier points were hand examined. Nearly all outliers were in areas of high and varied slopes. One of the largest clusters of outliers, shown below, sits in an area where slopes are rarely less than 5% (shown by the green color) and often exceed 12% (shown by the red color).



Not all of the flooding in Larimer County was characterized by outliers. In the Loveland Area, where the Big Thompson River flooded, the damaged was highly characterized by the floodplain.



Probabilistic Modeling

To try and quantify the relationship slope might have to damage points, choice modeling was used. While choice modeling is not typically used for this sort purpose, it was hypothesized that its probabilistic nature made it adaptable enough to get a sense of factors were most important.

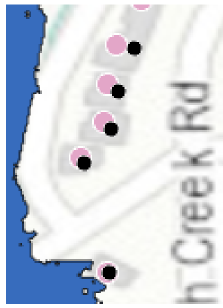
Typically, with choice modeling, one choice is used as the base, and variables that are separate from the choice are only included in the utility expression in the other model. Since this is a "yes" or "no" choice model, the model must be adapted a bit for these purposes. Since the characteristics of the point remain the same for both "choices", the utility for being "undamaged" is set to be a constant, and Biogeme selects that constant in a way that maximizes the number of times the utility function for "damaged" is higher than the utility function for "undamaged" when the structure is actually damaged, and vice versa.

To help with data management, the Estes Park area served as the data for this attempted model. Estes Park saw the most damage outliers, and its diverse terrain made it an ideal candidate for testing factors not directly related to flood extents. FEMA also had Estes Park Structures data set available, which was identical to the address point data set, but had additional attributes assigned to each point, though not whether it was structurally damaged. Several of these points had null address values, mostly in Rocky Mountain National Park, and these points were eliminated from the data set.

To prepare the data for analysis, several steps needed to be taken in GIS. First, the structures data set had to be amended to include whether the point was in the flood extents. In this region, the flood extents covered a larger region than the FIRM flood plain. Whether the structure was in the FIRM flood plain was also recorded. This was done by converting the shapefiles into rasters, then extracting the raster values to the points. Slope data was also incorporated this this way.

Next, by visual inspection, it was clear that the damage points were not assigned the same coordinates as the address points. This made adding a damage column to the Estes Park Structures attribute table a little more difficult. Each damage point, with a few exceptions, appeared to be equivalent to an address point, just assigned a slightly different coordinate.

This likely arose from the challenge of assigning a single point to a building that has area. Below, the damage point is shown in black, while the building point is shown in pink



Using the "Near" tool, the distance to the nearest damage point, as well as the ID of the damage point, was added to the attribute table. The data was then exported to excel, where logic functions assigned a value of "1" to the damage variable for the entry if the distance to the closest damage point was lower than any other entry that was closest to that data point, and if that distance was less than 50 feet. This method was probably not 100% accurate, but at maximum error, damage would be assigned to the wrong building, but most characteristics about that building were likely the same as the building it was meant to be assigned to. However, no evidence of mis-assignment was found.

Next, some descriptive statistics of the data set were performed.

Total Number of Buildings	7459
Total Number of Damaged Building	111
Number of Buildings within the Flood Extents	57
Percent of Damaged Buildings within 100 feet of flood extents	33.4%
Percent of Damaged Buildings within the Flood Extents	9%

Several models were run, testing out different variables, and most did not result in particularly relevant t-statistics. The inclusion of some non-geographic variables, such as when the house was built, did seem to hold some significance on a similar order to the variables of focus: HAND, flood extent, and slope.

One representative input for Biogeme was as follows:

```
[ModelDescription]
ESTES PARK DAMAGE PROB

[Choice]
DAMAGE

[Beta]
// Name Value  LowerBound UpperBound  status (0=variable, 1=fixed)
ASC_UNDAMAGED   0         -10000        10000       0
BETA_HAND       0         -10000        10000       0
BETA_SLOPE      0         -10000        10000       0
BETA_YEARBUILT  0         -10000        10000       0
BETA_EXTENTS    0         -10000        10000       0

[Utilities]
// Id Name  Avail  linear-in-parameter expression (beta1*x1 + beta2*x2 + ... )
  0  UNDAMAGED one   ASC_UNDAMAGED
  1  DAMAGED   one   BETA_HAND * IVTT_HAND  + BETA_SLOPE * SLOPE + BETA_YEARBUILT * YEARBUILT + BETA_EXTENTS * EXTENTS

[Expressions]
// Define here arithmetic expressions for name that are not directly
// available from the data
one = 1
```

This model resulted in the following coeffcients:

Variable	Coeffcient	t-statistic
Undamaged Constant	1.435	1.32
HAND	-0.135	-0.678
Flood Extent (dummy variable)	1.205	0.835
Slope	0.062	0.507
Year House was built	-0.00023	-0.405

Using the utility functions, a utility for “damage” and “undamaged” can be calculated. These can then be converted into probabilities using the function:

$$P_{damage} = \frac{e^{Udamage}}{e^{Uundamaged} + e^{Udamaged}}$$

A more intuitive interpretation may be that if the utility for damage is calculated to be greater than the Undamaged utility, which stays constant at 1.435, the property has a greater than 50% chance of being damaged.

None of the variables meet a t-test standard of 2, so while this model isn’t usable, the statistics are enough to extract some interpretation from the coefficients. Perhaps most telling is that the extent of the flood, while the closest to be significant, is not nearly as significant as we would expect. This gives some quantitative weight to what the maps of the damage points implied. As we would expect, the higher the HAND value, the lower the likelihood of damage, as implied by the negative sign. The positive sign on slope implies that higher

With choice modeling, the fit of the model can only be meaningfully compared to another model of the same data set, and there isn't a simple statistic to express how well the data is suited to being modeled. If such a statistic did exist, this model would probably show the equivalent of a low "r" value, as there were so few damage points, and a wide variety of characteristics among them. For the purposes of this report, this model is still useful in telling us which variables had impact, and to what degree that impact.

Though a significant model could not be found, the results are promising enough that with more expertise and experimentation, a non-floodmap based model for risk assessment could be found. Other things that could be explored are distance to floodplain variables, weighting variables by distance to floodplain, and using the average slope of the surrounding area instead of just the slope the point itself.

Conclusions

While criticism of the FIRM map program are certainly not new, the 2013 Colorado Floods certainly highlighted their shortcomings. ArcGIS is a powerful tool for quick visual assessment, and was powerful in identifying outlying damage points, and building a data set around those points. The question becomes, how should the FEMA insurance program move forward? When homeowners experience damage from flooding when they weren't eligible to purchase insurance, how should their recovery be funded? The Colorado 2013 rainfall event was also highly unusual, so does it make sense to amend the current system for an extremely unlikely circumstance? These are definitely questions being worked on, and ArcGIS will remain a powerful part of answering them.

It was fairly clear that the data set from FEMA isn't comprehensive to all damage the damage that the flood caused. A more comprehensive data set would make for much better modeling, but the extent of more minor damages throughout Colorado may have been too widespread for a cohesive data set to be assembled.

While this particular type of modeling is probably not the most suitable for risk assessment purposes, it did highlight that there are other factors for consideration that might be predictive of where damage might occur. Assembling the data, and cleaning it up for modeling in ArcGIS was time consuming, but ArcGIS certainly helped to visually identify what portions of the data needed to be eliminated for an analysis that made sense, whereas just looking at the data in spreadsheet form may have hidden unwanted points. Several efforts are being done to improve risk assessment, at both local and federal levels. As supercomputing availability widens, experimenting with more advanced models becomes more feasible. The results of the model in this study were not very statistically usable, but they at least suggested that a model for flood risk based on multiple features may be worth exploring.

This study also highlighted some of the strengths of HAND modeling. While there were still damage points outside the lower hand values, HAND offered an explanation for many of the values outside of both the flood extents and the flood plains.

The effects of the 2013 Colorado Flood are still seen throughout the state in 2018, with significant repair projects still underway. However, the most lasting impact the flood may be the way it changes the way the country approaches flood risk.

References

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[2] Kimbrough, Robert and Robert Holmes. “Flooding in the South Platte River and Fountain Creek Basins in Eastern Colorado.” USGS, 2015. https://pubs.usgs.gov/sir/2015/5119/sir20155119.pdf. Accessed Nov 30, 3018.

[3] National Weather Service. “Exceedance Probability Analysis for the Colorado Flood Event, 9-16 September 2013.” National Oceanic and Atmospheric Administration. Sep 17, 2013. http://www.nws.noaa.gov/oh/hdsc/aep_storm_analysis/8_Colorado_2013.pdf. Accessed Nov 30, 2018.

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[5] Coffman, Keith. “Property losses from Colorado flood projected at about $2 billion.” Reuters, Sept 18, 2013. https://www.reuters.com/article/us-usa-colorado-flooding-idUSBRE98H1BA20130919. Accessed Nov 30, 2018.

[6] Moody, John. “Estimates of Peak Discharge for the September 2013 Floods”. USGS. Sept 17, 2015. https://www.awra.org/meetings/Denver2015/doc/PP/powerpoint/Session%2042%20350%20Moody.pdf. Accessed Dec 1, 2018.

Data Sets Used

FEMA 2013 Colorado Flood Event:
https://data.femadata.com/Region8/ColoradoFlooding_2013/

Larimer County GIS: https://www.larimer.org/it/services/gis/digital-data

TACC HAND: https://web.corral.tacc.utexas.edu/nfiedata/HAND/

USGS DEM: https://viewer.nationalmap.gov/advanced-viewer/