HISTORIC FLOODING IN TIMARRON LAKES OF CREEKSIDE PARK NEIGHBORHOOD

CE 394K: GIS for Water Resources – Fall 2018

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An investigation of the inundation depths of historic and recent storms in a residential area of The Woodlands, Texas that resulted in a lawsuit against the developers and engineers responsible for the construction of the neighborhood.

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1 Introduction

1.1 Objective

Timarron Lakes is an upscale neighborhood located in The Woodlands township north of Houston, Texas that began development in 2011. After Hurricane Harvey hit in August 2017, around 350 homes flooded in this residential area. Now nearly 500 homeowners are being represented in a lawsuit against The Woodlands Development Company L.P., the Howard Hughes Corporation, and LJA Engineering Inc. The lawsuit presents claims against these developers of gross negligence for constructing a neighborhood in a 500-year floodplain without taking proper measures to reduce the effects of flooding, even with the knowledge of major flooding in recent decades. This analysis will map and compare the inundation depths of the most severe flooding events in the area of the Timarron Lakes neighborhood over the past few decades.

1.2 Motivation

When Hurricane Harvey hit the Houston, Texas area in 2017, I was just beginning my senior year as a civil engineering student at The University of Texas at Austin. My family, however, was back home in The Woodlands dealing with the aftermath of one of the largest rain events that has ever impacted the state of Texas. Hurricane Harvey resulted in an approximate $125 million dollars' worth of damage and the flooding of tens of thousands of Texan homes, including my grandparents' home, located in the Timarron Lakes section of the Creekside Park neighborhood in The Woodlands, Texas (NOAA, 2018). My grandparents fortunately evacuated their home before the storm made landfall, but returned to discover that the house that they purchased in 2015 had experienced 10 inches of flooding inside. Some of the resulting damage and cleanup process of their home can be seen in the right image of Figure 1 below. The left image of Figure 1 below shows flooding in the Timarron Lakes neighborhood after Hurricane Harvey passed through.

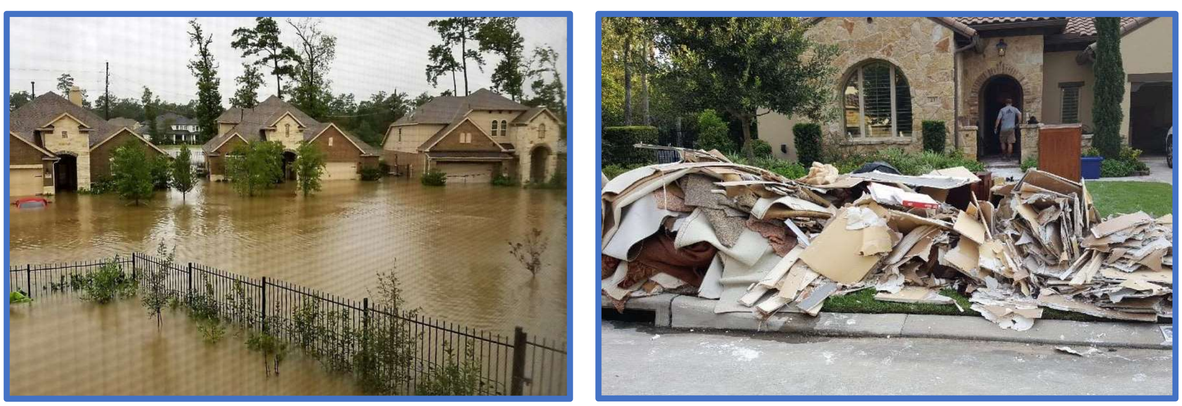

Figure 1: Left – 2017 Flooding in Timarron Lakes. Right – Resulting damages.

Interestingly, Hurricane Harvey was not the first flooding event that this relatively new and upscale residential area has experienced. After Memorial Day weekend in 2016, the streets of Timarron Lakes and a few of the houses experienced flooding, although not as intense as Hurricane Harvey in 2017. For example, at my grandparents' house, the Memorial Day 2016 floodwaters filled their yard and driveway, but only reached the edge of their front porch instead of making it inside their home.

These two recent flooding events resulted in nearly 500 homeowners being represented in a lawsuit against the development and engineering companies responsible for the planning of the Timarron Lakes neighborhood. The lawsuit claims that the developers planned and built homes in a 500-year floodplain without taking proper precautionary measures to reduce the effects of flooding, even with the knowledge of major, 500-year magnitude, flooding events in the area in recent decades. After reading these claims online, I decided to investigate the outcome that would occur if these major historic storms, that the developers knew about prior to the construction of the neighborhood, were to hit this area again today, would Timarron Lakes be prepared, or would it experience inundation? If the neighborhood were to flood under these historic conditions, how would it compare to the recent flooding that it has already experienced since being developed?

2 Background

2.1 Neighborhood Development

The Timarron Lakes neighborhood began development in 2011 as a section of the Creekside Park subdivision within The Woodlands township. This location is represented by the red pin positioned to the northwest of central Houston in the subset map shown in Figure 2 below. The right image of Figure 2 below displays a portion of The Woodlands Creekside Park West General Development Plans, including a dark green boundary around the sections of houses that this analysis was decided to be focused on (The Woodlands, 2018).

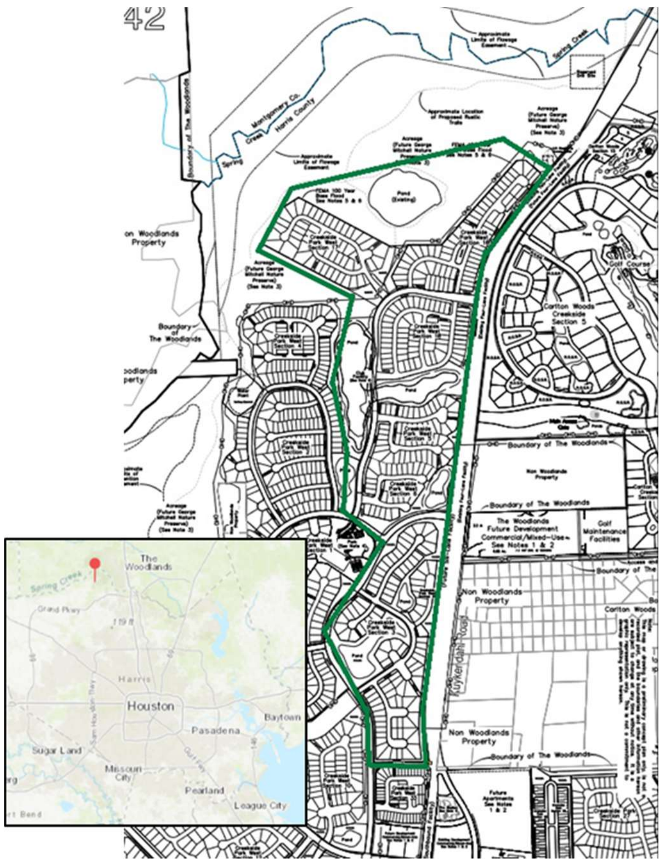

Figure 2: Left – Location in reference to Houston. Right – Neighborhood boundary of focus.

The dark green boundary illustrated in Figure 2 above is an arbitrary selection and was drawn based on boundaries described on developer's websites and numbers of homes affected by flooding reported in online news articles. It can be noticed from Figure 2 above that the development is bordered by Spring Creek to the north and west. The proximity to this stream caused a significant portion of the neighborhood's land to be located within the FEMA 100-year floodplain prior to its development, as seen in the 1996 FEMA Flood Insurance Rate Map in Figure 3 on the next page. It can be observed that the land that some homes were built on was even once a small lake (Schweinle Lake in Figure 3).

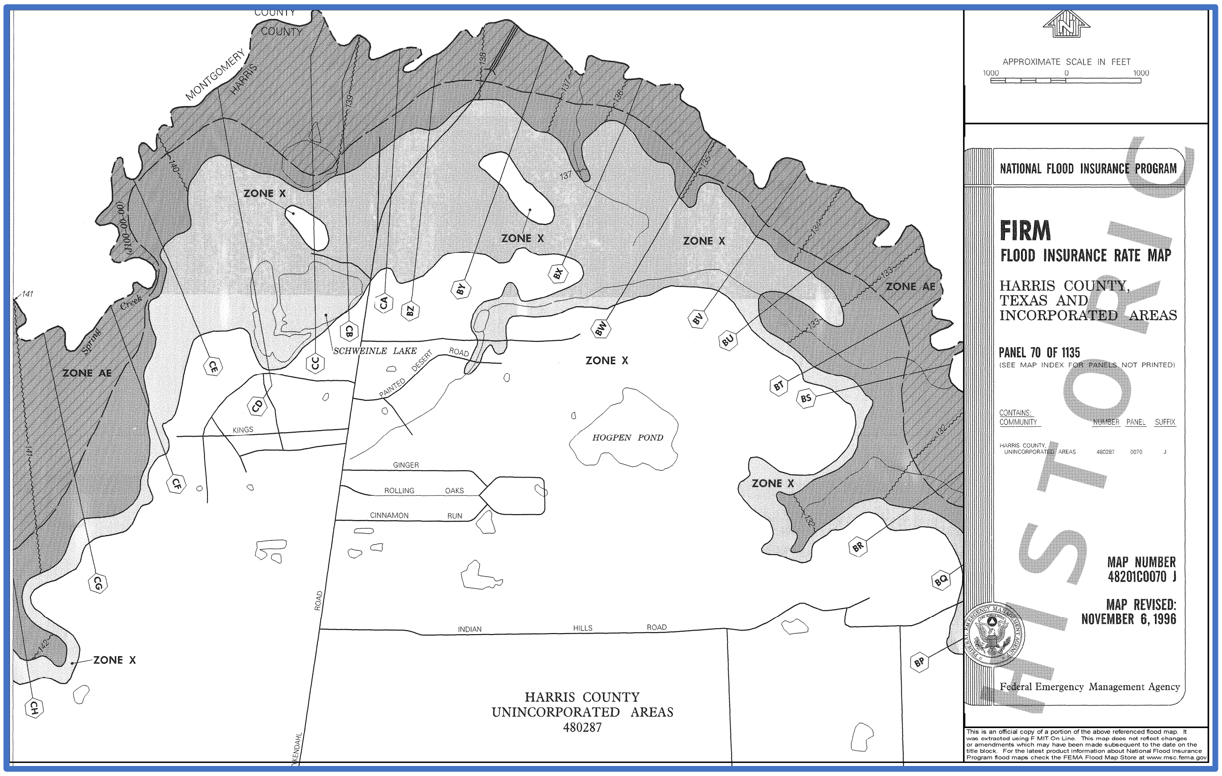

Figure 3: 1996 FEMA Flood Insurance Rate Map.

Given the existing conditions of the land from the historic FEMA flood map in Figure 3 above, the developers were required to raise the elevation of a large portion of the land in order to be able to legally develop it (FEMA FMSC, 1996). A note about this can be read if a closer look is taken to the General Development Plans, as pointed out in Figure 4 on the next page. The development note claims that "portions of some lots in the area have been or will be filled to raise elevations above the FEMA 100-year base flood elevation" and that an application to revise the FEMA 100-year floodplain would be sent out accordingly (The Woodlands, 2018).

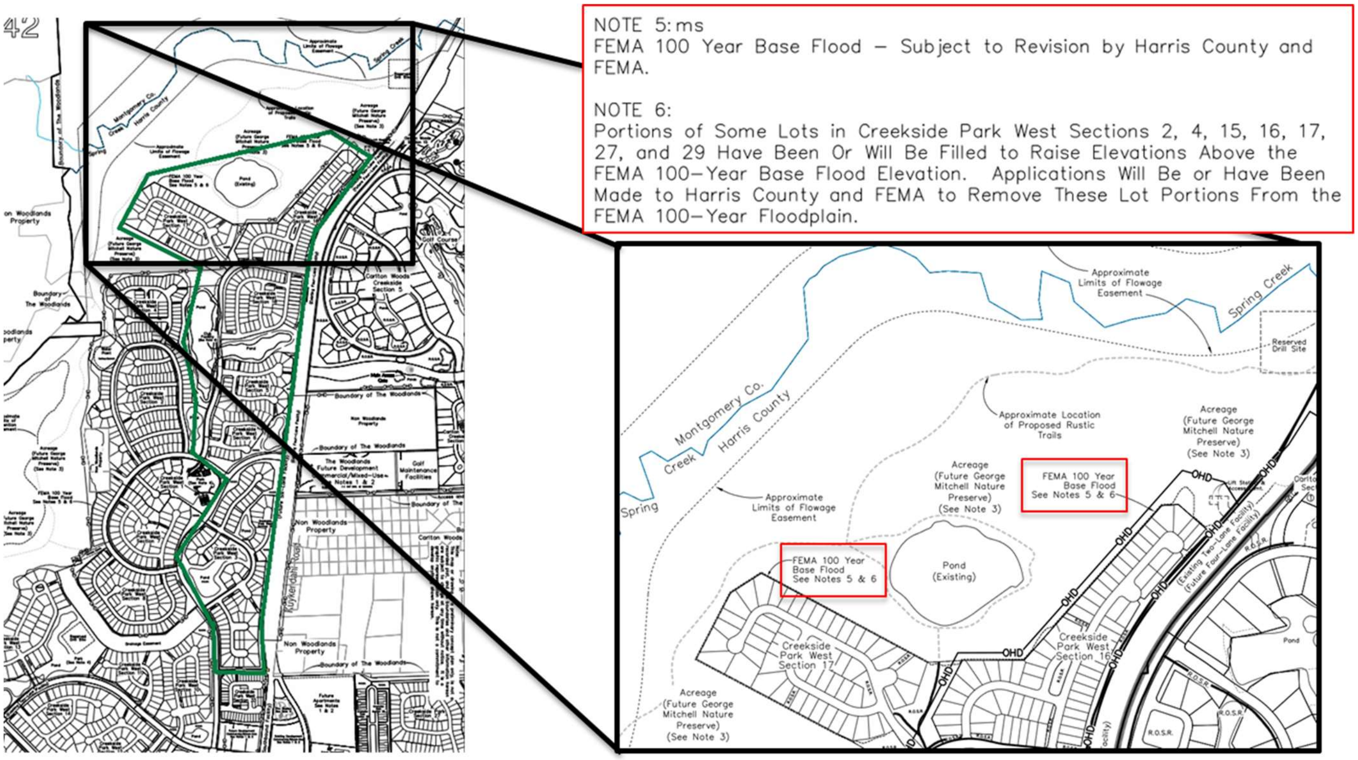

Figure 4: Note about 100-year floodplain revisions.

As a result of this small disclaimer in the General Development Plans, over 80,000 cubic yards of dirt were used as fill to raise the affected lots above the base flood elevation. In several cases, the lots were raised 10 inches above the 100-year base flood elevation, but in a few cases, some were only raised 1.2 inches above the required minimum elevation (The New York Times, 2017). Raising these lots barely above the 100-year base flood elevation is enough to requalify the land as being in the 500-year floodplain instead and can therefore be built on. However, it puts several of these lots at risk of ground subsidence. Ground subsidence is the possibility of the fill soil settling over time, to the point that the elevation of the house can sink back below the 100-year base flood elevation, and therefore increasing the risk of flooding.

After all of the fill was put into place to raise the elevation of the lots, the FEMA floodplain revisions were approved. The current, effective FEMA floodplain map, retrieved from the FEMA National Flood Hazard Layer (NFHL) Viewer, can be examined in Figure 5 on the next page (FEMA, 2018).

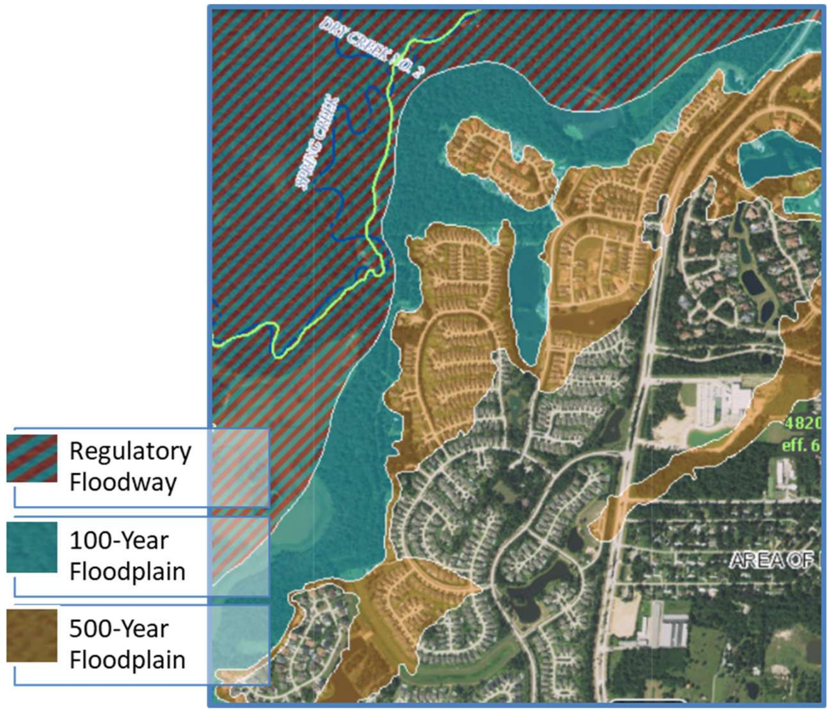

Figure 5: Current effective FEMA floodplain map.

It can be observed from the FEMA floodplain map in Figure 5 above that a significant portion of the lots in this neighborhood section now reside in the 500-year floodplain. However, the 100-year floodplain borders the backyards of several of the residents. This proximity does not provide much room for error and these lots should certainly still be considered at risk of flooding. However, in the state of Texas, the Department of Insurance only requires the purchase of flood insurance if your house is placed in the 100-year floodplain (Texas Department of Insurance, 2018). Therefore, almost no homes in this neighborhood were required to purchase flood insurance, even though several of them have already experienced two flooding events within the past three years.

2.2 Historic Storm Data

To collect data about the historic and recent storms that have impacted the area of the Timarron Lakes neighborhood, I used the Harris County Flood Control District's (HCFCD) Flood Warning System (FWS) website. Data from two different HCFCD gages along Spring Creek nearest to the neighborhood were studied. The two gages had similar data, but Gage 1040 located along Spring Creek at FM 2978 was older and had more historical data, so that one was selected to include data from for this project. The location of HCFCD Gage 1040 can be seen in Figure 6 on the next page.

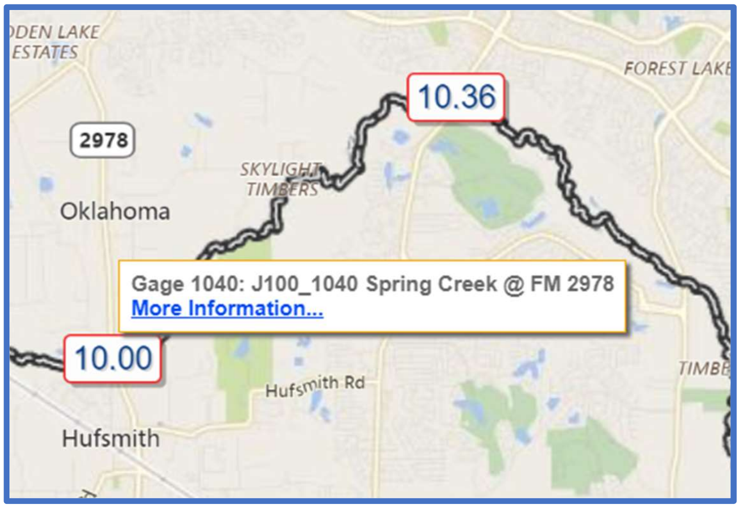

Figure 6: Map of Harris Country Flood Control District stream gages.

The stream elevation data reported from the HCFCD Gage 1040 was examined and four historic storm events with some of the highest stage heights recorded at that location were selected. These storm events included an October 1994 storm, Hurricane Allison in 2001 (both occurred prior to the development of the Timarron Lakes neighborhood), then the Memorial Day 2016 storm, and Hurricane Harvey in 2017. According to the statistical data from this location, the two older, more historic storms qualified as having a magnitude greater than a 500-year flooding event, while the two more recent storms qualified as having a magnitude just greater than a 100-year flooding event for this area. The stage height information was collected for each storm and is reported in Table 1 below. It can be noticed that both of the historic storms had stage heights higher than both of the recent storms, and that Hurricane Allison reported the largest stage height on record with 11.9 m.

Table 1: Historic storm stage height data.

Storm Event	Stage Height (m)	Stage Height (ft)	Flood Frequency
October 1994	10.38	34.06	< 0.2%
Hurricane Allison 2001	11.90	39.04	< 0.2%
Memorial Day 2016	9.86	32.35	< 1%
Hurricane Harvey 2017	10.13	33.24	< 1%

3 GIS Process

3.1 Building a Base Map

In order to map the impact of the four historic storms in ArcGIS, the process had to begin with building a base map of the area of interest. This started with downloading input data for the Texas-Gulf Water Resource Region 12 from the National Flood Interoperability Experiment (NFIE) geospatial database from the Hydroshare website (C. Fagan, 2015). This database included five feature classes of National Hydrography Datatset (NHD) flowlines, catchments, waterbodies, subwatersheds, and stream gages in the region. The Select Layer by Attribute tool was used with an expression to identify subwatersheds that had HUC_8 values equivalent to 12040102, which is representative of the Spring subbasin watershed, which is the subbasin that the Timarron Lakes neighborhood is located in. These selected subwatersheds were then merged to create a new layer for the outline of the basin. The catchments and flowlines that were located within this basin boundary were then selected and copied to new feature classes. The resulting Spring basin with catchments and graduated flowlines from these steps can be seen in the first image of Figure 7 below.

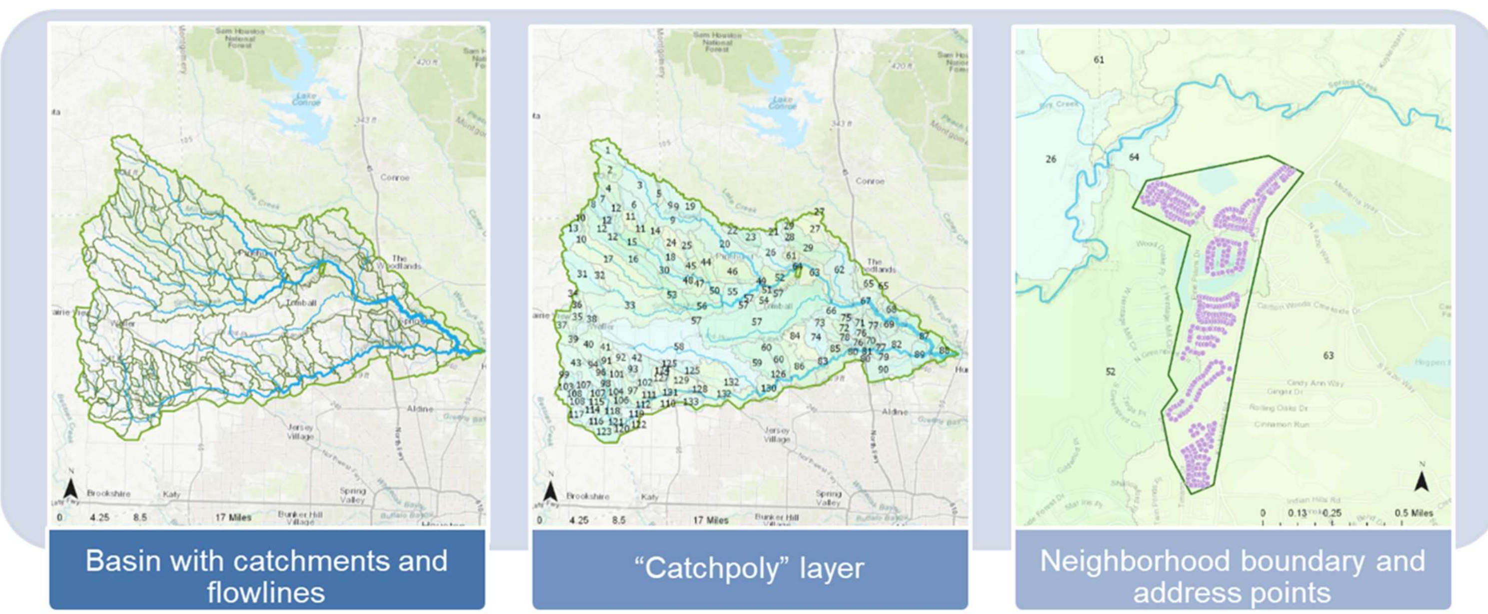

Figure 7: Steps in building a base map.

A drawn polygon was created as a new feature class that represented the boundary of interest for this study around the Timarron Lakes neighborhood. Address points were downloaded from the Hurricane Harvey GIS story map for the Houston area and then selected by location within the neighborhood boundary and exported to a new feature class layer (D. Maidment, 2018). This neighborhood boundary and the 662 resulting address points within it can be seen in the third image of Figure 7 above.

3.2 Height Above Nearest Drainage (HAND)

A 10-meter resolution digital elevation model (DEM) from the National Elevation Dataset (NED) was obtained from the National Map for the area (National Map, 2018). The NHD flowlines were then delineated to create a stream raster that was consistent with the DEM flow directions. This DEM-derived stream raster was then used to calculate a raster for the height above nearest drainage (HAND) for the whole basin using tools from the Hydrology Toolbox in ArcGIS. These HAND values were then later used to determine inundation depths in the area, as described in the next section of this report. The resulting map of the HAND raster displayed across the basin is shown in Figure 8 below.

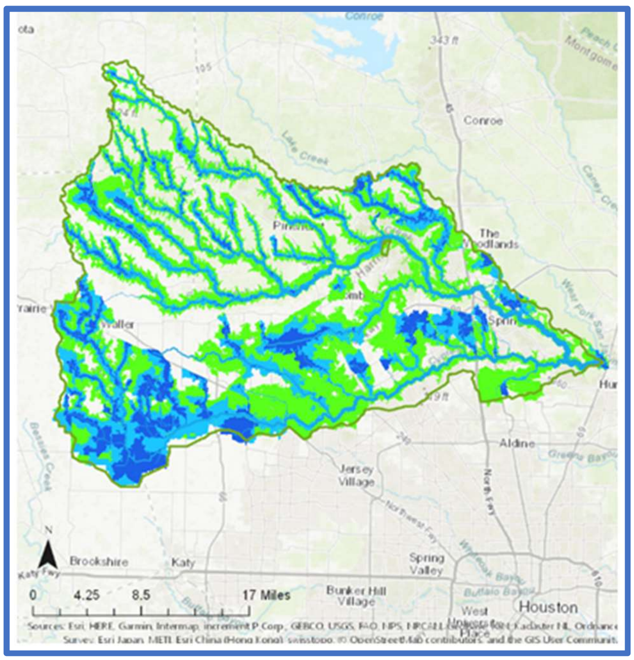

Figure 8: Height Above Nearest Drainage for entire basin.

The DEM for the basin was also used to derive a catchment polygon feature class called ‘catchpoly’. In total, there were 133 catchpoly’s derived for the entire basin. The neighborhood boundary feature class that was created as part of the base map overlapped with three of these catchpoly’s - #52, #63, and #64. These are the three catchpoly’s that are used in the Model Builder analysis discussed in the next section. The second image in Figure 7 on the previous page shows the labeled catchpoly layer over the entire basin of interest. The third image in Figure 7 on the previous page also illustrates how the neighborhood boundary overlaps catchpoly’s #52, #63, and #64.

3.3 Model Builder: Determining Inundation Depths and Flooded Address Points

The Model Builder function in the ArcGIS program was utilized to determine the inundation depths and to identify the flooded address points for each historic and recent storm. A screenshot of the Model Builder flowchart that was created for this project is displayed in Figure 9 below, and a more detailed description of the numbered sections follows the image.

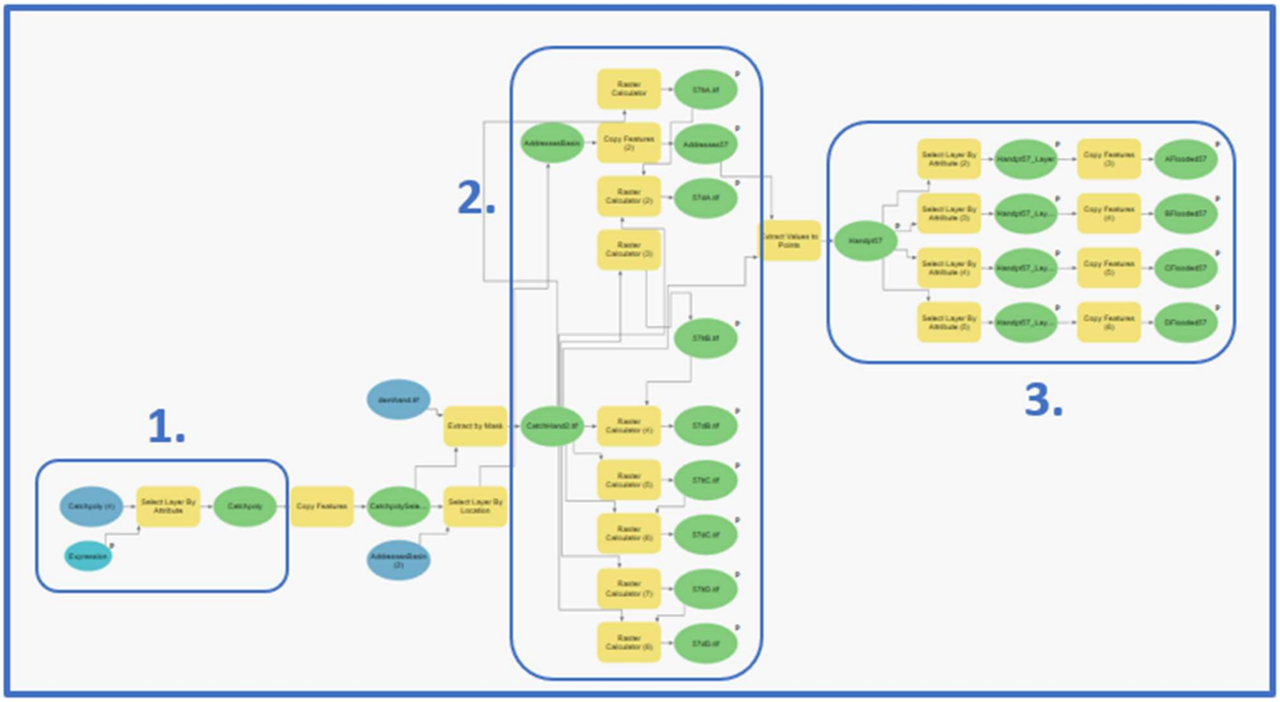

Figure 9: Model Builder used to determine inundation depths and flooded addresses.

Description of Model Builder:

1.) Since there were three separate catchpoly's that the neighborhood boundary overlapped, the first part of the Model Builder used the Select Layer by Attribute tool with an expression that could be edited to select one of the three catchpoly's by their unique ObjectID. This Model was then run three times, once per catchpoly, in order to gather the unique results for each one.
2.) The second portion of the model uses the Extract by Mask tool to create a new layer of the HAND raster that is only within the selected catchpoly. This new HAND layer within the catchpoly is then used with the Raster Calculator tool to calculate the inundation depths that would occur for each storm's given stage height. This results in a raster layer of inundation depths for each of the four historic storms within the area of the selected catchpoly.
3.) The third portion of the model uses the Extract Values to Points tool in order to assign the HAND values from the HAND raster in the selected catchment to the individual address points within the selected catchment. These HAND values are assigned to the address points as RasterValues. Then, the Select Layer by Attribute tool is used with an expression that identifies all of the address points

that have HAND RasterValues less than the given stage height for each of the four historic storms, meaning that these selected address points would experience inundation by the storm. These selected address points are then copied into four new layers that represent all of the flooded address points in the selected catchment for each of the four historic storms.

After running the Model Builder model three times for each of the three catchments that the neighborhood boundary overlapped, some further reorganization of resulting layers was required. The resulting layers of flooded address points for each storm within each catchment were combined across all three catchments using the Merge tool. Then the Select Layer by Location tool was used to select all of the flooded address points for each storm that were located completely within the neighborhood boundary feature class, then the Copy Features tool was used to create a new layer of flooded address points for each storm that were only within the neighborhood boundary of focus for this project.

Finally, the symbology was updated for each of the resulting layers and arranged in layouts that can be viewed in the following Results section of this report.

4 Results

4.1 Maps of Inundation Across the Neighborhood

The results from GIS include a map of the Timarron Lakes neighborhood that reveals the number of homes that would be predicted to experience flooding if each of the four historic storms were to hit again today, including estimated inundation depths of the surrounding area. Figure 10 below compares the inundation maps of the two most recent historic storms to hit the area, the Memorial Day 2016 storm and Hurricane Harvey in 2017. The left image of Figure 10 displays the map for the Memorial Day 2016 storm that had a stage height of 9.86 meters and resulted in a total of 331 flooded homes. The right image of Figure 10 displays the map for Hurricane Harvey in 2017 that had a stage height of 10.13 meters and resulted in the flooding of 362 homes in the Timarron Lakes neighborhood. This value is relatively close to the 350 value of flooded homes that was reported in news articles about the hurricane damage (The Houston Chronicle, 2018).

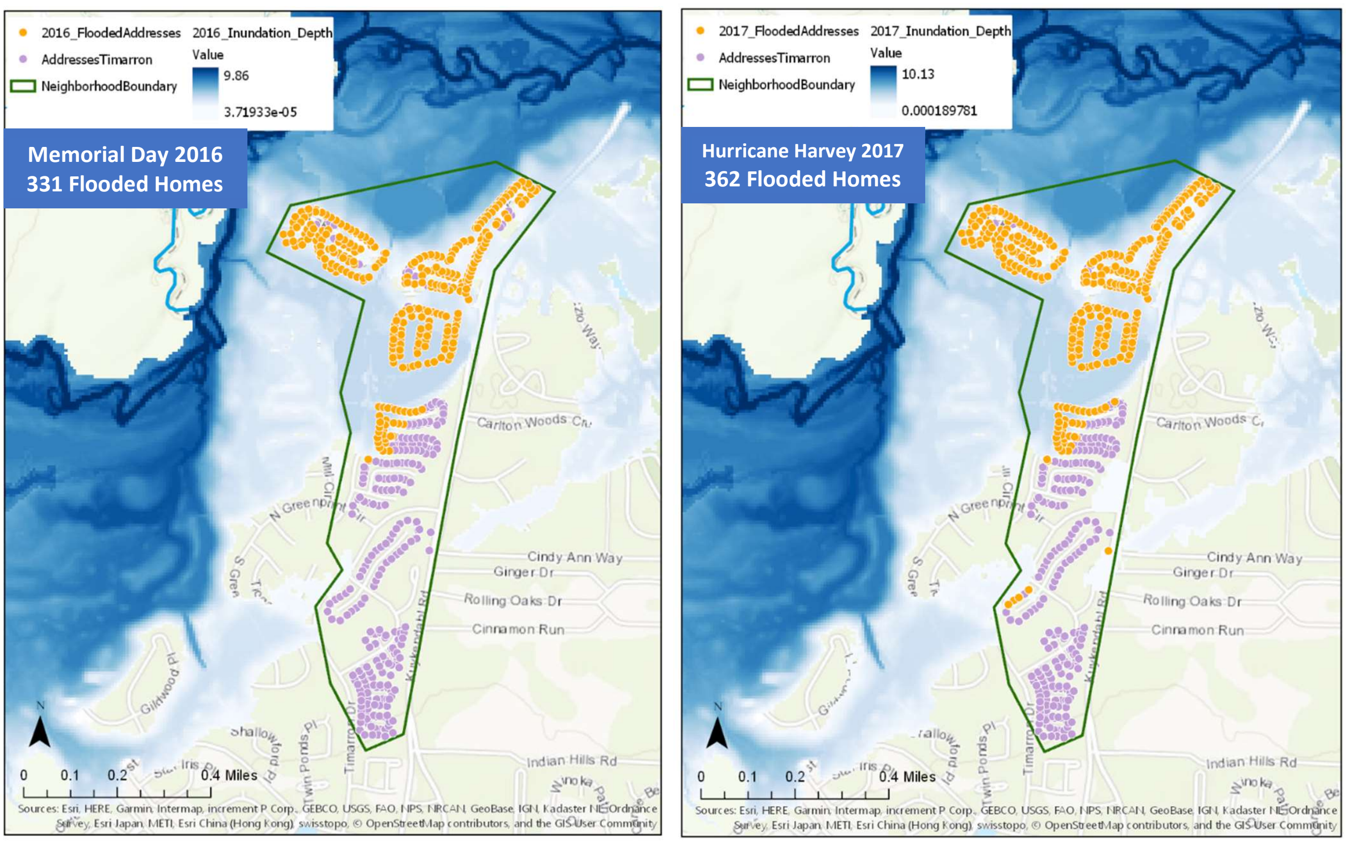

Figure 10: Left – Memorial Day 2016 Inundation Map. Right – Harvey 2017 Inundation Map.

Figure 11 below compares the inundation maps of the two older historic storms to hit the area, the October 1994 storm and Hurricane Allison in 2001. The left image of Figure 11 displays the map for predicted inundation depths of the October 1994 storm that had a stage height of 10.38 meters and would result today in an estimated total of 388 flooded homes. The right image of Figure 11 displays the map for the predicted inundation depths for Hurricane Allison in 2001 that had a record stage height of 11.09 meters and would result today in the flooding of an estimated 560 homes in the Timarron Lakes neighborhood.

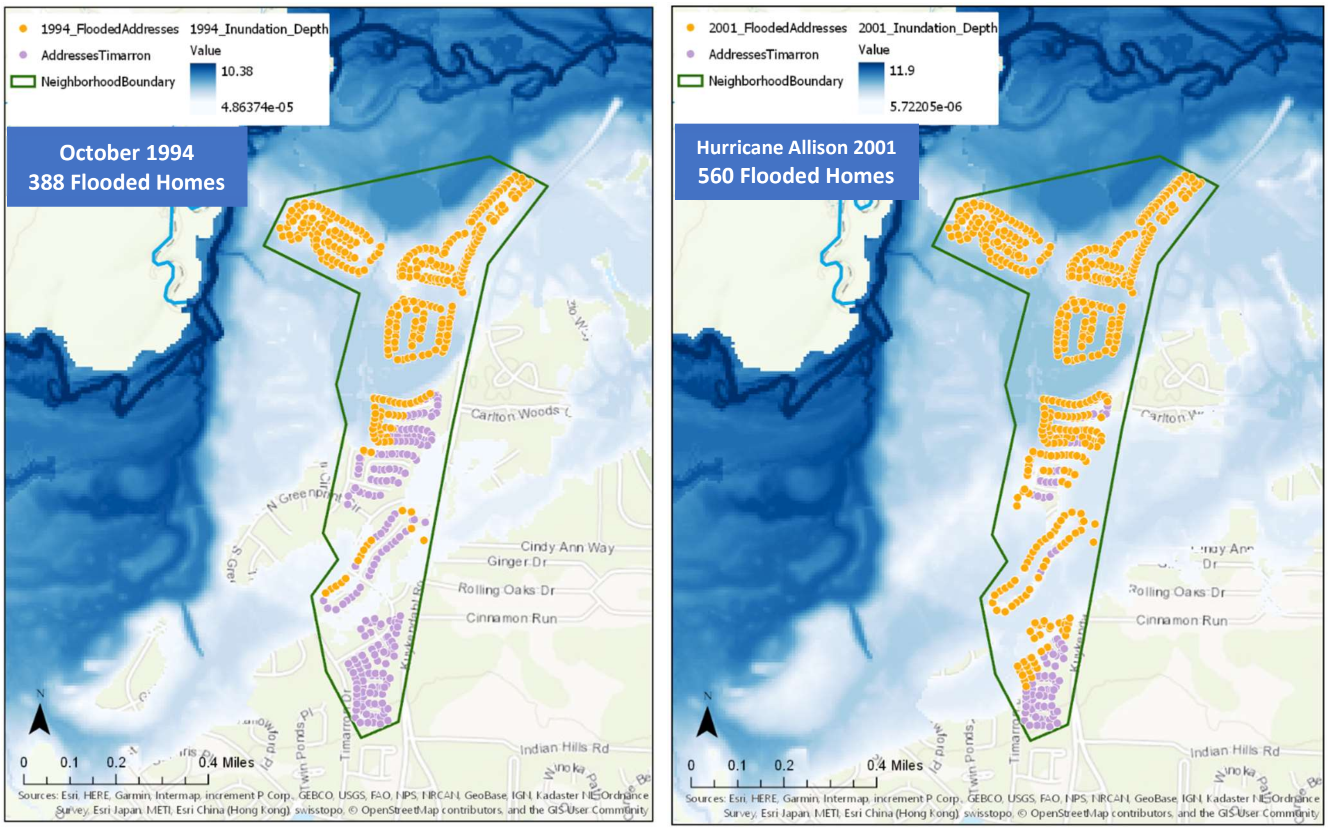

Figure 11: Left – October 1994 Inundation Map. Right – Hurricane Allison 2001 Inundation Map.

It can be interpreted from the maps in Figure 10 and Figure 11 that the storms with the higher recorded stage heights would result in a larger number of homes flooded in the Timarron Lakes neighborhood, and deeper inundation depths, if these storms were to hit again today. Table 2 on the next page summarizes the estimated number of flooded homes, out of the 662 total homes, in the neighborhood area per storm event. Table 2 also compares the percentage of total homes in the neighborhood area that the storm event would inundate.

Table 2: Results for flooded homes per storm event.

Storm Event	# of Homes Flooded	% of Total Homes Flooded
October 1994	388	58.6%
Hurricane Allison 2001	560	84.6%
Memorial Day 2016	331	50.0%
Hurricane Harvey 2017	362	54.7%

From Table 2 above, it should be noted that the magnitude of each of these four historic storms would flood a staggering 50% or more of the homes within the study area of the Timarron Lakes neighborhood. The maximum damage predicted by this GIS modeling process results from a storm with the same magnitude as Hurricane Allison that would flood 84.6% of homes in the area if it were to occur today.

4.2 Distribution of Inundation Depths

This report also compares the distribution of inundation depths for each storm event. The HAND value data was collected from the GIS attribute tables of the feature classes of the flooded address points and then subtracted from the stage height value given for each storm to determine the inundation depth value per address point and then graphed using Excel. The resulting histograms for each of the four historic storm events can be compared in Figure 12 on the following page. Figure 12 also summarizes the average inundation depth experienced by the address points in the study for each storm.

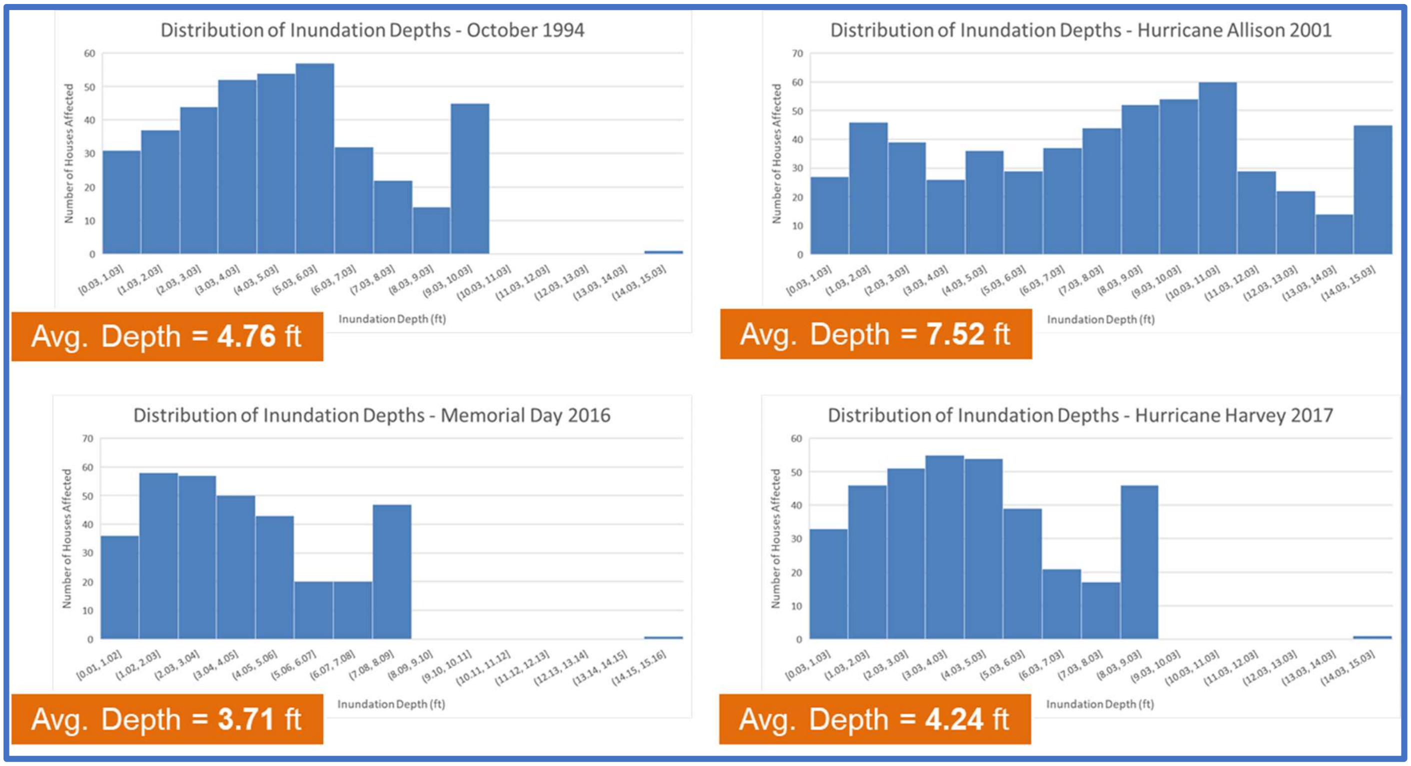

Figure 12: Distribution of Inundation Depths for each storm event.

From Figure 12 above, it can once again be understood that the highest magnitude of damage that would result in this neighborhood would be from a storm the size of Hurricane Allison. According to the results of this project, a storm with the same magnitude of Hurricane Allison in 2001 could reach an extreme inundation depth of up to 15 feet, and an average inundation depth of 7.52 feet, within the Timarron Lakes subdivision. Comparatively, the Memorial Day 2016 storm only reached an average inundation depth of 3.71 feet across the address points in this neighborhood. From this study, Hurricane Harvey in 2017 caused a maximum flooding depth of almost 9 feet in the neighborhood. This value fits into the highest recorded inundation depth range of 8-10 feet reported by the National Hurricane Center for Hurricane Harvey in the state of Texas (NOAA, 2018).

5 Conclusions

5.1 Limitations

Although the results from this GIS study seem reasonable compared to reported facts, there are some potential causes of error to note. Firstly, the observed depth of inundation in my grandparents' house after Hurricane Harvey was 10 inches, while the GIS map reported 24 inches of inundation for their address point. This brings up the fact that the GIS address point reports the inundation depth taken from one specific coordinate, whereas in real life, the inundation depth may vary across the property. Meaning that, in the case of my grandparents' house, the GIS address point may be reporting the inundation depth from their yard or driveway, where the flooding would be deeper than the 10 inches specifically inside the house.

Another potential source of error occurs due to the inconsistencies between the delineation of the catchpoly layer using the D8 method, while the HAND raster is calculated using the D infinity method. This can cause a skew in some inundation depth values that could result in higher values than what was physically observed. Finally, it should be emphasized that any mapping or modeling of rain events can never fully, accurately portray what occurred in reality. However, this project is believed to be within reasonable range and representation.

5.2 Conclusions

Civil engineers as a profession are supposed to "hold paramount the safety, health, and welfare of the public" in all the work that they do (National Society of Professional Engineers, 2018). However, on occasion, a project like this one brings up the potential conflict in the engineering profession of lawful versus ethical practices. Specifically, for this example, the engineering and development companies were within lawful jurisdiction to construct the Timarron Lakes neighborhood on the land that they did after bringing in the necessary amounts of fill to revise the area to be within the 500-year floodplain. However, with the knowledge of risk of ground subsidence in the area, especially with lots that were only raised a few inches, and with the knowledge of the magnitude of the historic storms that have been studied in this report, then perhaps the development of this land area should have been cautiously reconsidered.

Considering that four storms with high enough magnitudes to potentially flood more than half of the homes in the neighborhood area have occurred within the past 24 years, the developers most likely should have taken extra measures to invest in the longevity of the Timarron Lakes development. Instead of focusing on a quick profit and bare minimum requirements, the engineers should have further researched methods for minimizing the risk of flood damage in the area. These methods could include, bringing in more fill to raise the elevation of the lots above the 500-year floodplain, investing in a storm drain system and detention ponds with larger capacities, or not developing the land that was originally located within the 100-year floodplain at all.

This project also highlights the need for a possible reevaluation of the storm event frequencies and resulting floodplains in this area. This area of north Houston should consider updating city development codes and regulations to be based on the 500-year floodplain depth, instead of the 100-year floodplain depth, similar to the Austin Atlas 14 modification that is currently underway (City of Austin, 2018). Due to climate change and global warming, the National Weather Service is predicting that parts of Central Texas have higher probabilities of experiencing larger magnitude storms than previously thought (City of Austin, 2018). Considering this, the Timarron Lakes neighborhood is likely still at risk to experience the damaging effects from storms similar to the ones modeled in this study, and engineers and developers have a higher level responsibility than ever before to prepare and protect the public.

6 References

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Texas Department of Insurance: https://www.tdi.texas.gov/consumer/storms/flood-insurance.html

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