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A Study on the Lake Conroe Dam Release Following Hurricane Harvey

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CE 394K: GIS IN WATER RESOURCES

Table of Contents

List of Figures

List of Tables

1.0 Introduction

1.1 Background

Hurricane Harvey was a Category 4 hurricane that made landfall in Texas on August 25, 2017 [1]. While the United States has had its fair share of Category 4 hurricanes throughout history, the magnitude and size of Harvey's destruction was unrivaled in historical records with analysts dubbing Harvey as a 1-in-1,000-year flood [2]. Throughout the course of Harvey's 5-day downpour, roughly 27 trillion gallons of water were dumped over Texas and Louisiana with some weather stations in the Houston area registering more than 50 inches of rain [3]. To put this in perspective, this amount of water is equivalent to 1 million gallons of water *per person* in the state of Texas. This statistic is illustrated in Figure 1 [3]. The devastation incurred from Harvey included the destruction of more than 30,000 homes, the displacement of over 35,000 people to emergency shelters, and early estimates of $150 billion in recovery costs [3].

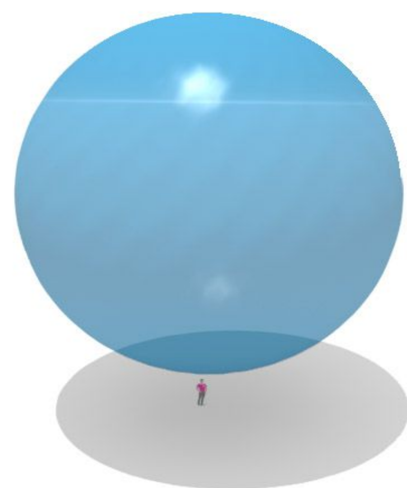


Figure 1. For Scale: Water Volume per Person

However, the physical water volume was not the only aspect of Harvey that affected the impacted communities. The existing infrastructure was put under additional strain and many experts have since called for a needed improvement in infrastructure resilience to better handle these catastrophic events [4]. The Lake Conroe Dam was one such structure that was unable to maintain safe operating levels under the threat from Harvey.

The Lake Conroe Dam is located on the West Fork of the San Jacinto River, about 54 miles north of Houston. The dam was completed in 1973 and consists of an earthfill embankment just over 11,300 feet in length with an emergency spillway located near the center of the embankment [5]. The crest elevation of the dam is 212 feet above mean sea level (MSL) and the normal water level is 201 feet MSL with an additional 6 feet flowage easement allowed for extreme storm events [6]. While there is technically an additional 5 feet available before the dam overtops, the operational protocol for the safe and structurally sound operation of the dam is based on the 207 feet MSL water level [6].

During Hurricane Harvey, unprecedented water levels prompted officials from the San Jacinto River Authority (SJRA), the government entity that has control of the dam, to release 79,141 cfs of water from the dam, a volume that approached the average volume pouring over Niagara Falls [7][8]. The SJRA's general manager, Jace Houston, made a statement about this necessary action claiming that the water would have been released regardless of their decision: either through the controlled release or over the dam's gate, which would have put the dam at risk of failure [8].

There has been much contention regarding the decision to release such a record flowrate of water from the dam, the previous record being 33,360 cfs in 1994 [8]. Since the release, there have been a number of lawsuits with over 250 involved individuals claiming that the SJRA released the floodwaters knowing the risks of flooding downstream of the dam and failed to adequately warn the residents of imminent flooding [8]. The majority of home and businessowners believe that their properties would not have flooded due to the Harvey rains, but instead were solely impacted by the dam release.

1.2 Problem Statement

This study aims to evaluate the impact of the Lake Conroe Dam release downstream of the dam, primarily through identifying flooded address points that resulted from the release flows. The SJRA provided a map of peak flows giving the peak inflow into Lake Conroe as well the peak release flowrate. This can be seen in Figure 2 below.

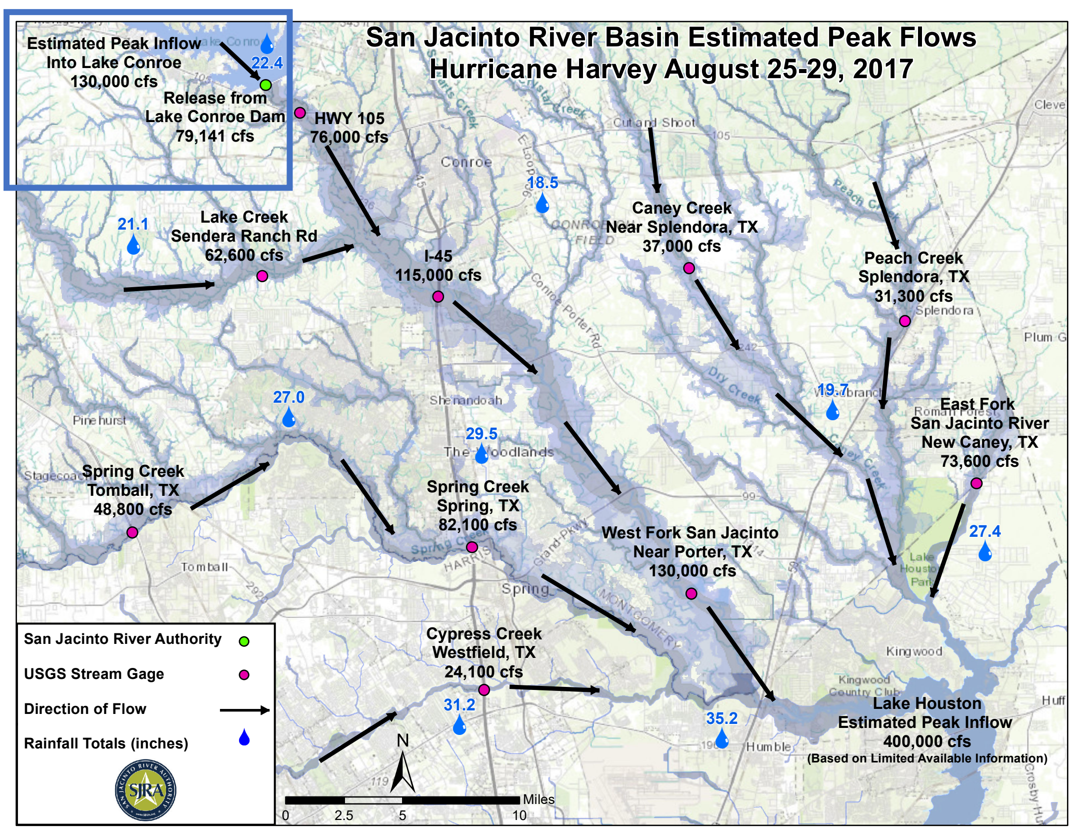


Figure 2. SJRA Map of Peak Inflows

This study will look at two scenarios by evaluating:

(1) Scenario 1: Impact due to the 79,141 cfs actual dam release
(2) Scenario 2: Impact that would have resulted from the release of the entire 130,000 cfs peak inflow into Lake Conroe (i.e. if the dam had not existed at all)

While there is other stream gage data reported on this map due to accumulation and rainfall, only the two flows of 79,141 cfs and 130,000 cfs will be considered for this study.

1.3 Data Sources

Table 1 below provides the sources for the main datasets used throughout this study.

Table 1. Data Sources

Dataset	Source	Use in the Study
Subbasin Characteristics	NFIEGeo Water Resource Region 12 [9]	The characteristics served as the basis for developing the basemap and included: stream gages, flowlines, waterbodies, subwatersheds, and catchments.
Hydrologic Unit Code (HUC) 8 Value	United States Geological Survey (USGS) [10]	The HUC 8 value served as the identification of the subbasin of interest and was used to delineate the subbasin.
Digital Elevation Model (DEM)	National Map [11]	The DEM served as the basis for delineating the stream network necessary to compute the Height Above Nearest Drainage.
Peak Inflow and Release Flow	San Jacinto River Authority [7]	The peak inflow into Lake Conroe and the peak release flowrate from the dam were essential in determining flooded stage heights to assess the affected address points.
Populated Places	US Census of Populated Places (within ArcGIS Pro)	The US Census provided the areas within the subbasin that had the largest population centers which served as the basis of focus area selection (i.e. where the most impact would occur).
Address Points	HydroShare Texas-Harvey Basemap [12]	The address points provided the physical property points that were necessary in evaluating the impact of the release waters and inundation depths.

2.0 Approach

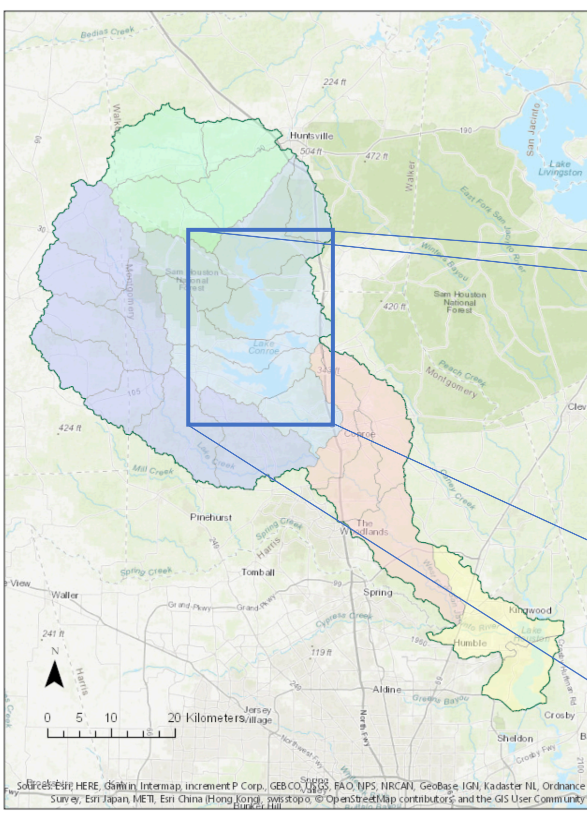
The objectives of this study were accomplished through three main steps:

(1) Creating a basemap of the area with associated characteristics
(2) Determining a focus area
(3) Utilizing Model Builder to perform the Height Above Nearest Drainage (HAND) analysis to assess the address points

2.1 Creation of Basemap

To start this analysis, a basemap had to be created for the area of interest. The National Flood Interoperability Experiment Geospatial Database, NFIEGeo, for the Texas Gulf Coast region was first obtained from the ArcGIS online map and imported into ArcGIS Pro [9]. This database contained all necessary stream gages, flowlines, waterbodies, subwatersheds, and catchments for the entire Texas Gulf Coast region. To delineate the desired watershed boundary, the Hydrologic Unit Code 8 (HUC 8) was utilized to identify the subbasin that housed the Lake Conroe Dam. Using the USGS Watershed Boundary Dataset, 12040101 was determined to be the HUC 8 of interest [10]. This subbasin consists of 5 watersheds and 25 subwatersheds as can be seen below in Figure 3.

Lake Conroe is located within the light blue watershed and the location of the Lake Conroe Dam can be seen labeled in the figure.



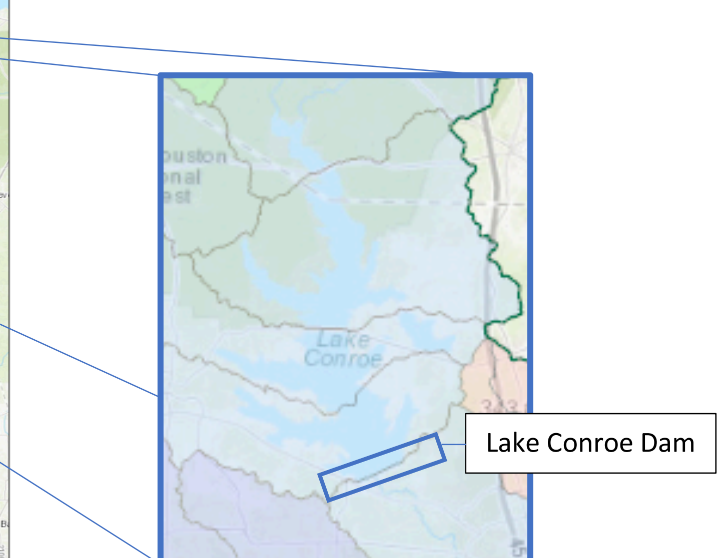


Figure 3. Watersheds and Subwatersheds

Prior to any further analysis, the flowlines and land cover for the subbasin were observed to understand the basic flow of water through the subbasin and identify the different types of landcover in the area. The NFIEGeo provided the National Hydrography Dataset (NHD) flowlines and the land cover was obtained from the USA National Land Cover Dataset (NLCD) Land Cover 2011 within the Living Atlas. The graduated flowlines and land cover distribution can be seen below in Figures 4 and 5, respectively.

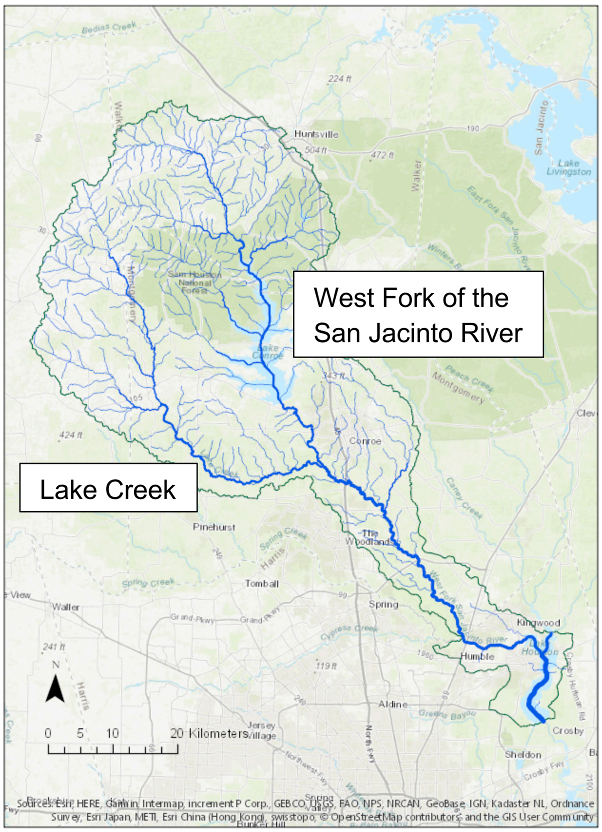


Figure 4. Graduated Flowlines

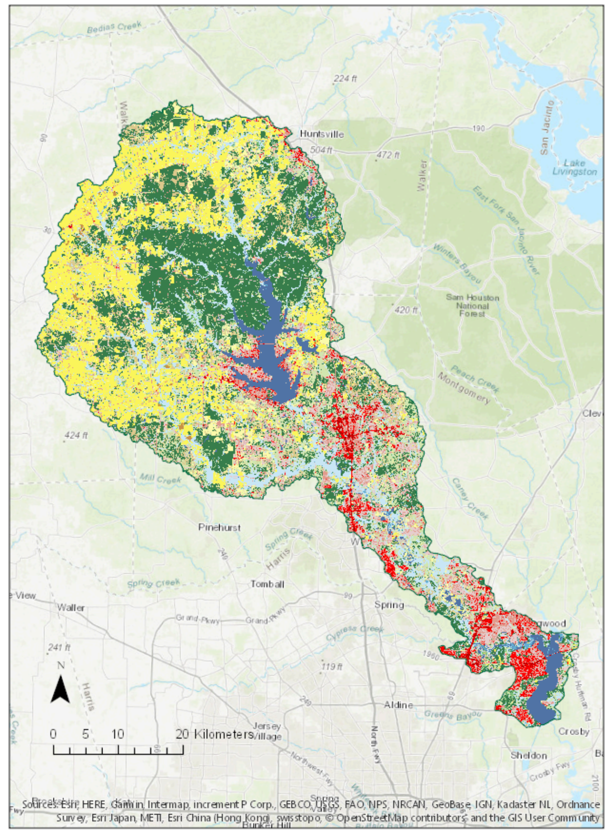


Figure 5. Land Cover Distribution

As can be seen in Figure 4, the West Fork of the San Jacinto River cuts directly through Lake Conroe and joins up with Lake Creek downstream of the dam before flowing into Lake Houston at the southeastern most area of the subbasin. The land cover distribution in Figure 5 depicts developed areas in red, most of which are located directly around the lake and scattered downstream of the dam. This statistic was utilized to determine the primary focus areas for this study and will be discussed further in Section 2.2.

The Digital Elevation Model (DEM) was then downloaded from the National Map with a 1/3 arc-second, 10 m resolution [11]. The subbasin fell between two datasets so they were merged and extracted to fit the subbasin area. From the DEM, a stream network was derived and utilized to calculate the Height Above Nearest Drainage (HAND). The HAND raster served as the basis for the evaluation of flooded stage heights and inundation depths in the analysis portion of this study. In addition to the stream network, catchment polygons (catchpolys) were also derived from the DEM and each harbor a derived drainage line that flows through the polygon. The resulting HAND map and catchpolys can be seen below in Figures 6 and 7, respectively.

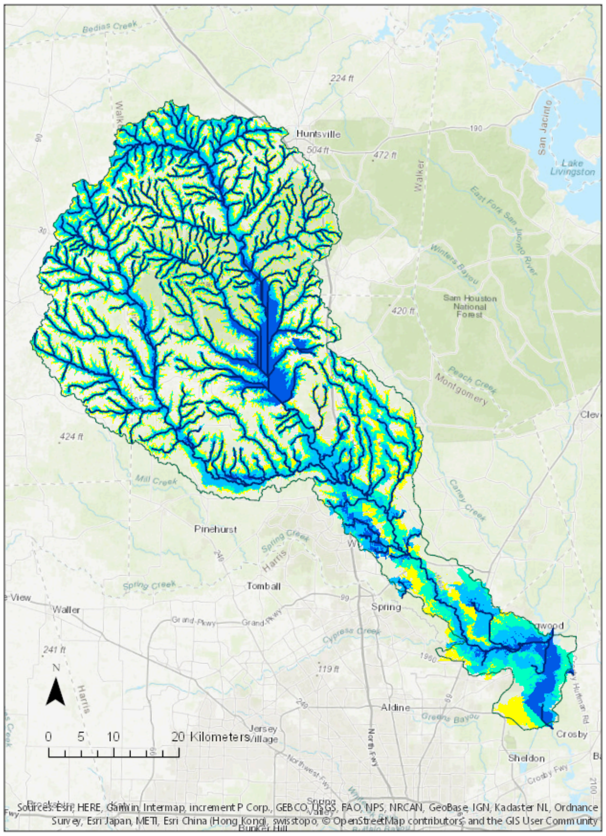


Figure 6. Height Above Nearest Drainage

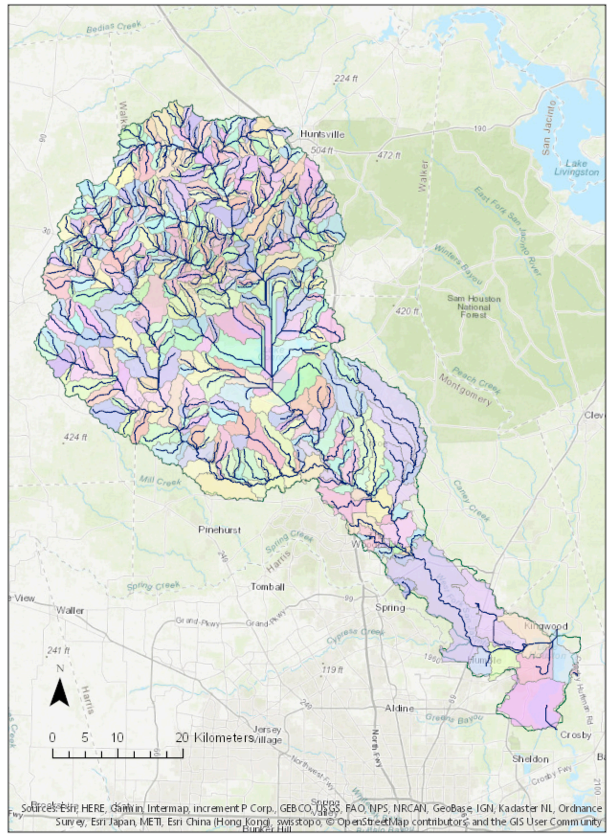
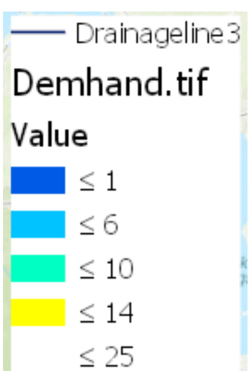


Figure 7. DEM Derived Catchpolys and Drainage Lines



The drainage lines can be seen in both figures as the navy lines throughout the subbasin. The HAND color scheme can be seen in the legend to the left where the units are in meters. As expected, the areas that are classified as waterbodies or flowlines have a HAND value of less than 1 meter, designating those entities as drainage points for water throughout the subbasin. In total, there are 562 catchpolys, represented by the multicolored polygons in Figure 7. The next section will detail the designation of the focus areas and corresponding catchpolys for this study.

2.2 Determination of Focus Area

The second step of this study was to determine a practical focus area that would be further analyzed.

There were two main criteria for determining a focus area:

(1) Location downstream of the dam

(2) Population centers (i.e. areas that would more likely be affected – flooded properties)

As noted in the previous section and referencing back to Figure 5, the land cover distribution showed the majority of developed land downstream of the dam. To further refine the focus area, the US Census of Populated Places was used to identify the areas that housed the major population centers within the subbasin. This was overlaid on the catchpoly basemap and can be seen below in Figure 8.

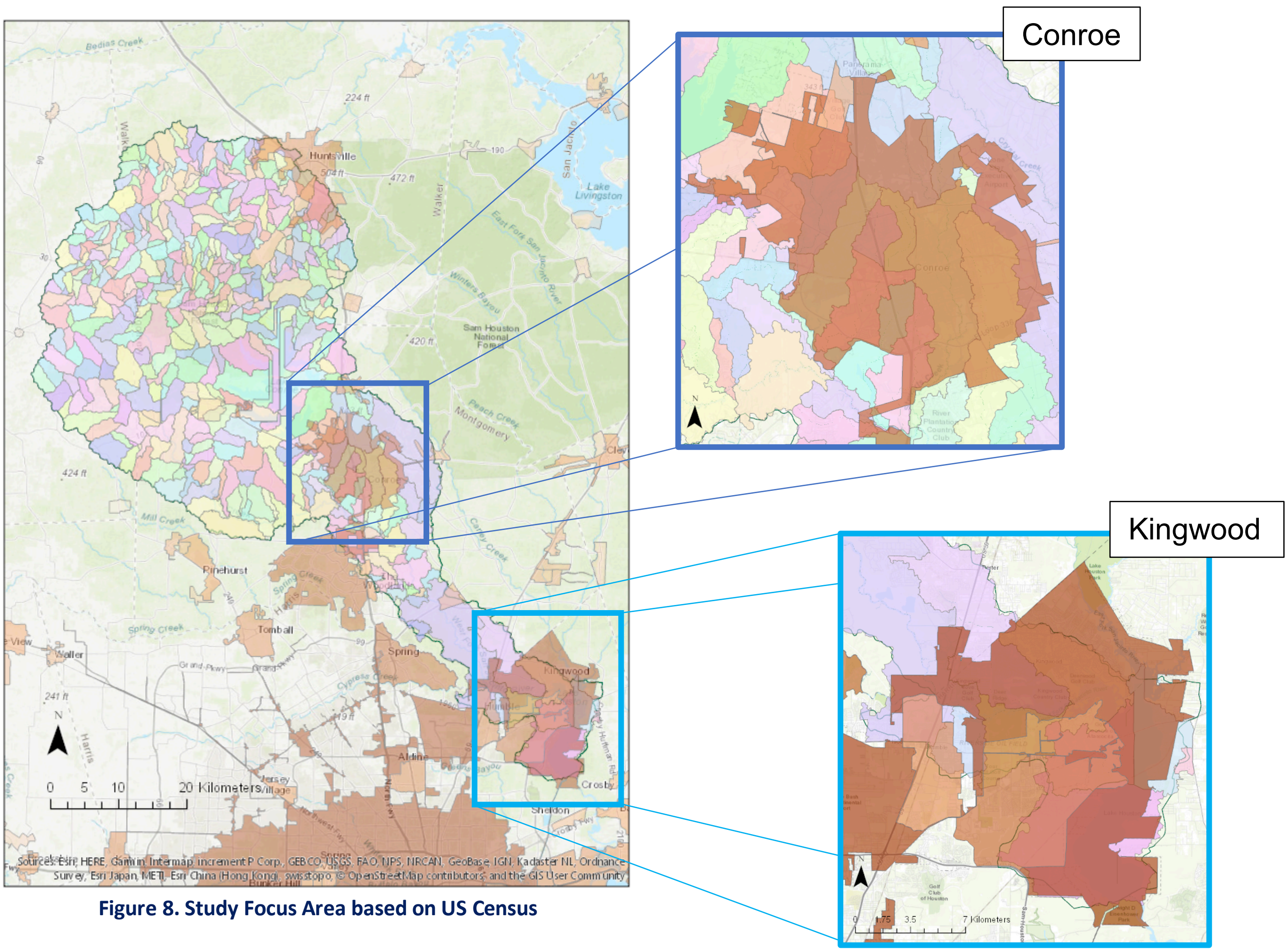


Figure 8. Study Focus Area based on US Census

As can be seen in Figure 8, two focus areas were selected for analysis: the Conroe region located immediately downstream of the dam and the Kingwood region located at the southeastern most portion of the subbasin. While these focus areas do not encompass the entirety of either city, they were designated as “Conroe” and “Kingwood” for easy referencing. Of these focus areas, a total of 22 catchpolys were analyzed, 16 in the Conroe area and 6 in the Kingwood area.

2.3 HAND Analysis

Once the initial base map was created and the focus area was chosen, the 22 selected catchpolys had to first be analyzed to obtain their flooded stage heights through the development of rating curves before the flooded address points could be identified. Model Builder was used for the majority of this section of analysis as the Object ID of each catchpoly could be parameterized. By adding the Object ID as a parameter within the model, once the steps and raster calculations were developed, the model could be run for each catchpoly by simply changing the Object ID in the Geoprocessing pane of ArcGIS.

2.3.1 Develop Rating Curves

The first stage in the HAND analysis was developing the rating curves for each catchpoly of interest. The rating curve shows the relationship between stage heights and their respective discharges. As the discharge for each modeled scenario was known, the flooded stage height could be interpolated from the rating curve for each catchpoly.

Prior to running the model, the length of the drainage line and the bed slope were manually identified for each catchpoly. To then develop the rating curves, the number of flooded cells, inundation depths, and slope raster were needed at various stage heights to obtain the parameters necessary for Manning's equation to calculate the corresponding discharge. Stage heights of 1, 6, 10, and 14 m were used. These scenarios were built into the Model Builder so that the desired parameters could be extracted after one run of the model. Figure 9 to the left provides an example of one of the rating curves and Figure 10 on the following page shows a screenshot of the Model Builder.

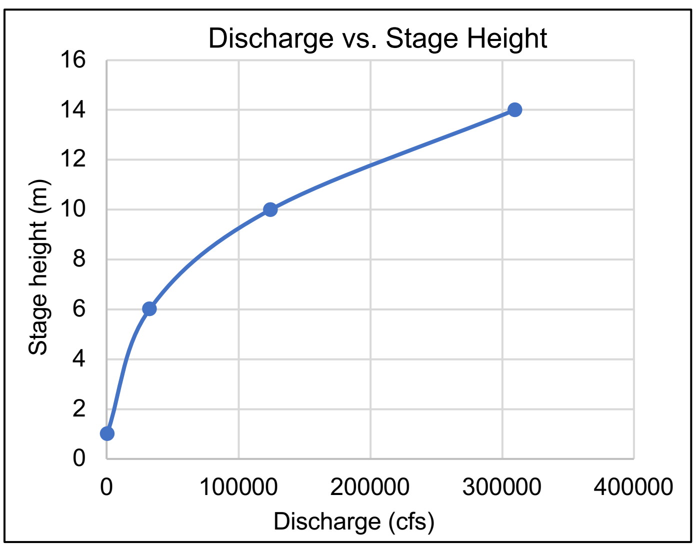


Figure 9. Sample Rating Curve for Catchpoly - Object ID 506

As can be seen in the rating curve, the obtained discharges were much higher than needed. For future work, a tighter range of stage heights could be used to develop a more refined rating curve. This will likely also give more accurate flooded stage heights.

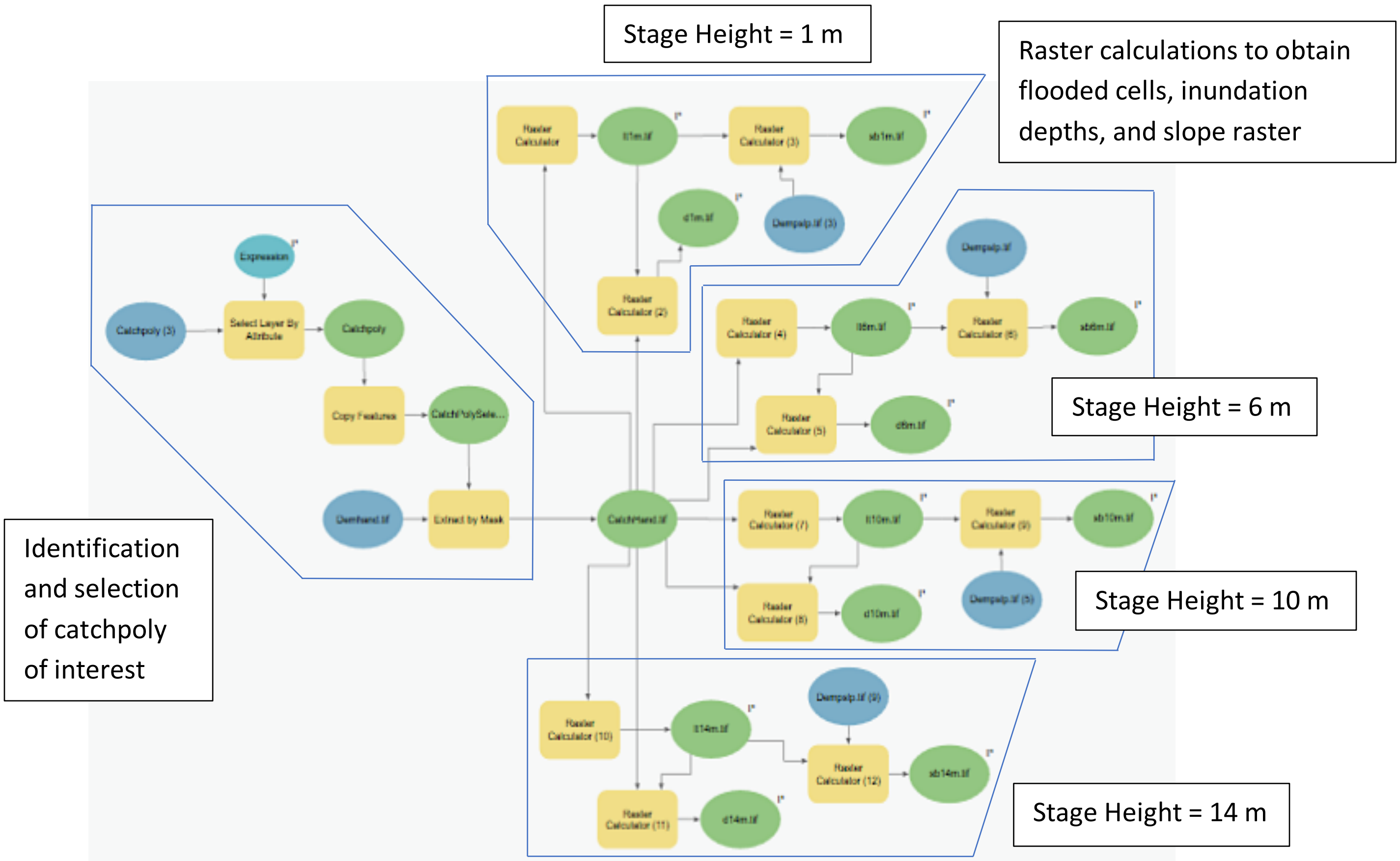


Figure 10. Model Builder for Rating Curves

2.3.2 Determine Flooded Stage Heights

After the rating curves were obtained, the flood stage heights were interpolated from the curve using the discharges for each scenario. The interpolation formula can be seen below:

$$y = y_1 + \frac{y_2 - y_1}{x_2 - x_1} * (x - x_1)$$

Where y refers to the flooded stage height (m), x refers to the known discharge for either scenario (cfs), x_1 and x_2 represent the calculated discharges from the rating curve (cfs), and y_1 and y_2 represent the corresponding stage heights (m).

The flooded stage heights were tabulated for each scenario within each catchpoly and can be seen in Table 2 in Appendix A.

2.3.3 Identify Flooded Address Points

Following the identification of flooded stage heights for each scenario, the flooded address points could be determined. The address points for the entire subbasin were obtained from the Hurricane Harvey story map [12]. A second Model Builder was created to identify the flooded address points by parameterizing both the Object ID so it could be run for each catchpoly and the flooded stage heights for each scenario. The model first extracted the address points for each catchpoly and overlaid the previously determined HAND raster to assess the HAND value at each address point. The flooded address points were then identified by evaluating which address points had HAND values that were less than the flooded stage height for each scenario. These steps produced a map of the address points subject to flooding for each scenario. Figures 11 and 12 show screenshots of the model builder and parameter options, respectively.

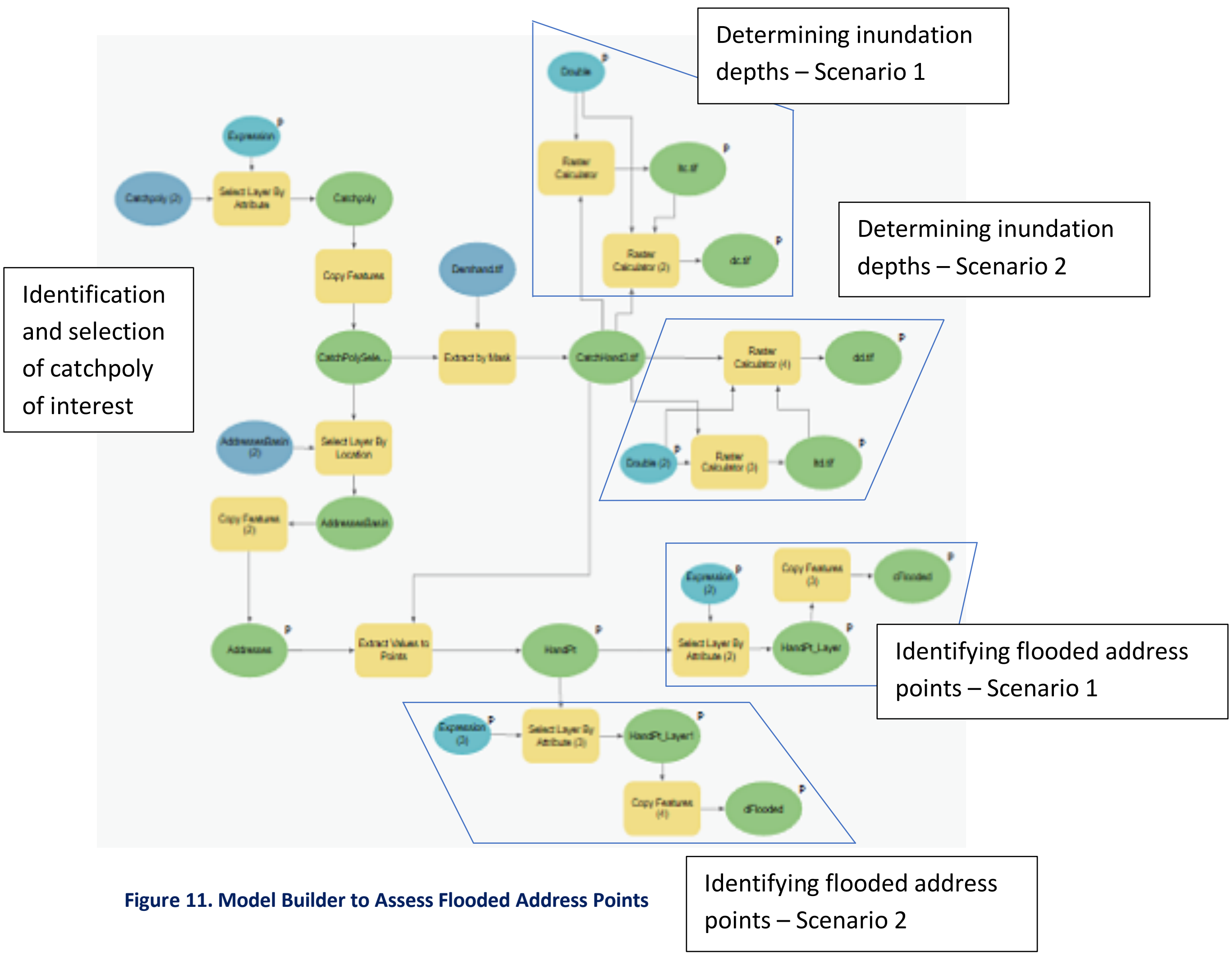


Figure 11. Model Builder to Assess Flooded Address Points

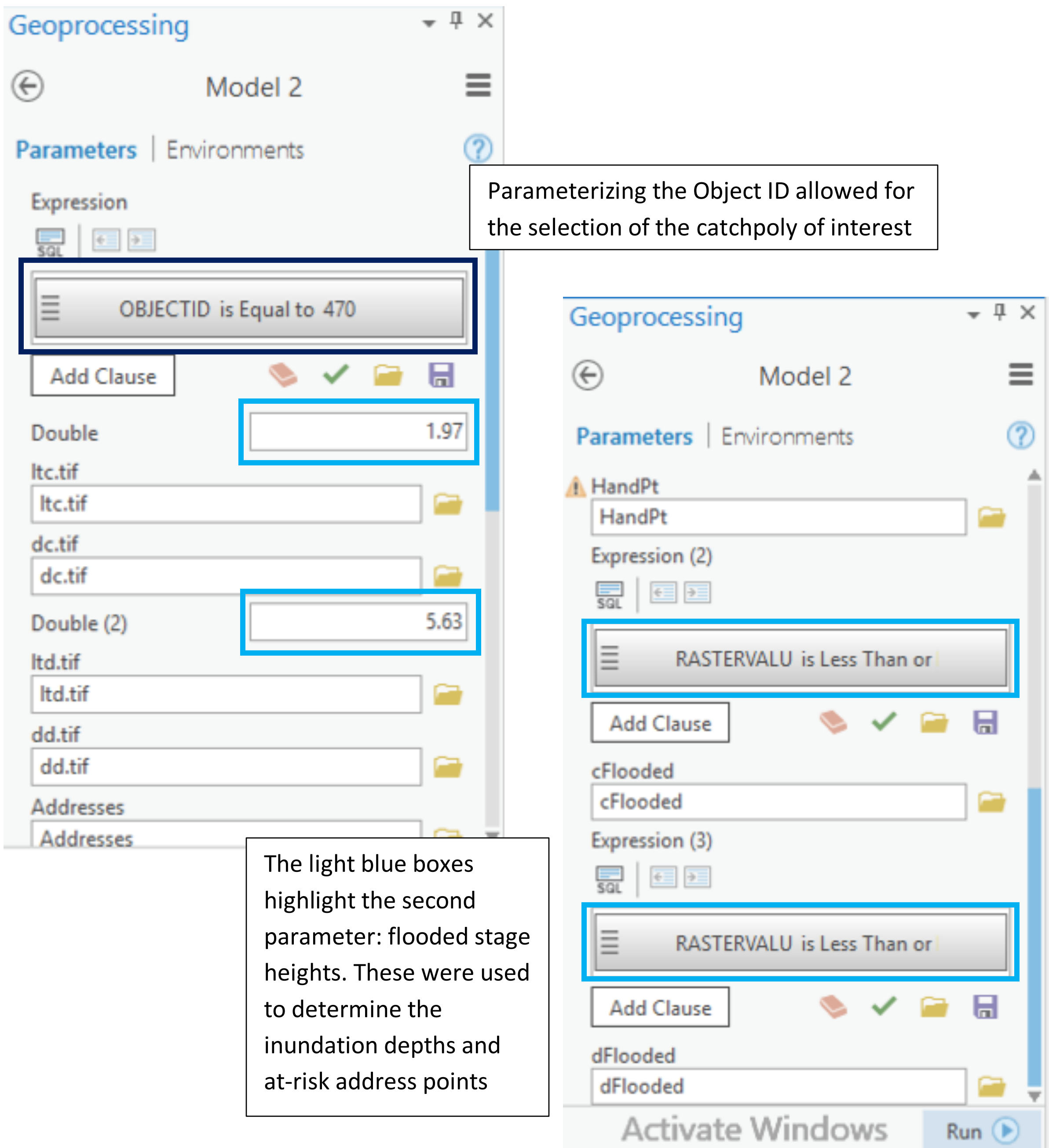


Figure 12. Parameter Options for Model Builder 2

3.0 Findings

The primary goal of this study was to evaluate the address points that were impacted from the dam release following Hurricane Harvey and additionally evaluate the impact had the dam not existed, allowing the entire 130,000 cfs to flow downstream. The findings can be seen below in their respective focus areas.

3.1 Conroe

In total, the 22 catchpolys analyzed within the Conroe focus area contained 24,341 address points. Of these, 3,322 were at risk of flooding due to the dam release and 5,506 would be at risk had the dam not existed at all. Figures 13, 14, and 15 represent the total address points, flooded address points due to the dam release, and flooded addresses due to the no-dam scenario, respectively.

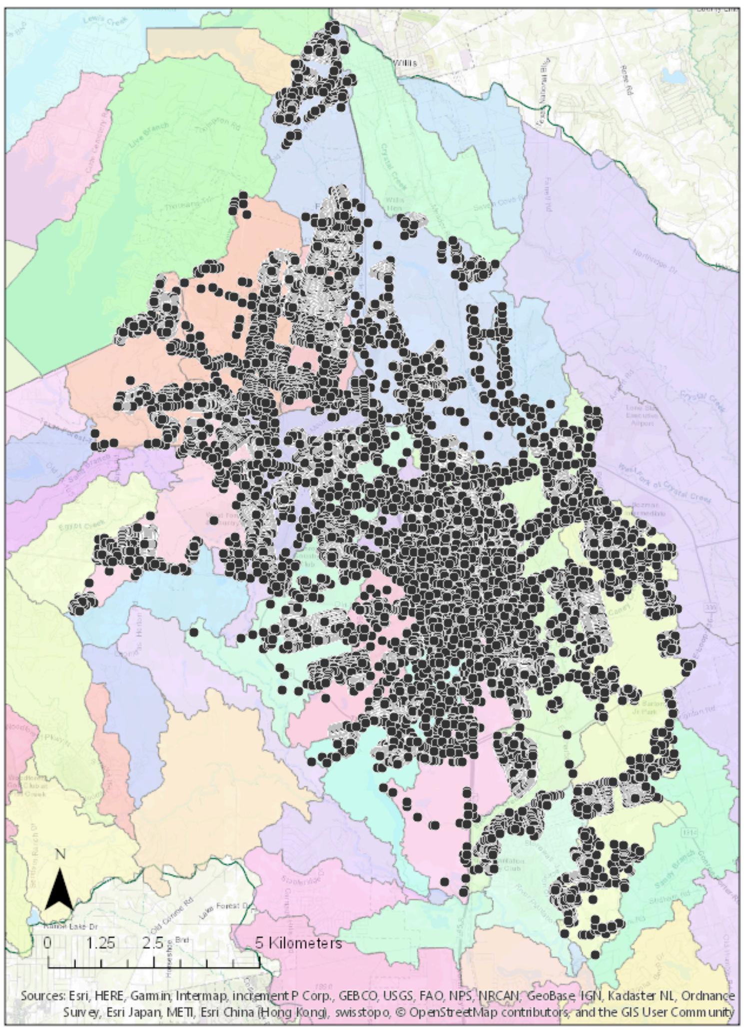


Figure 13. Total Address Points - Conroe

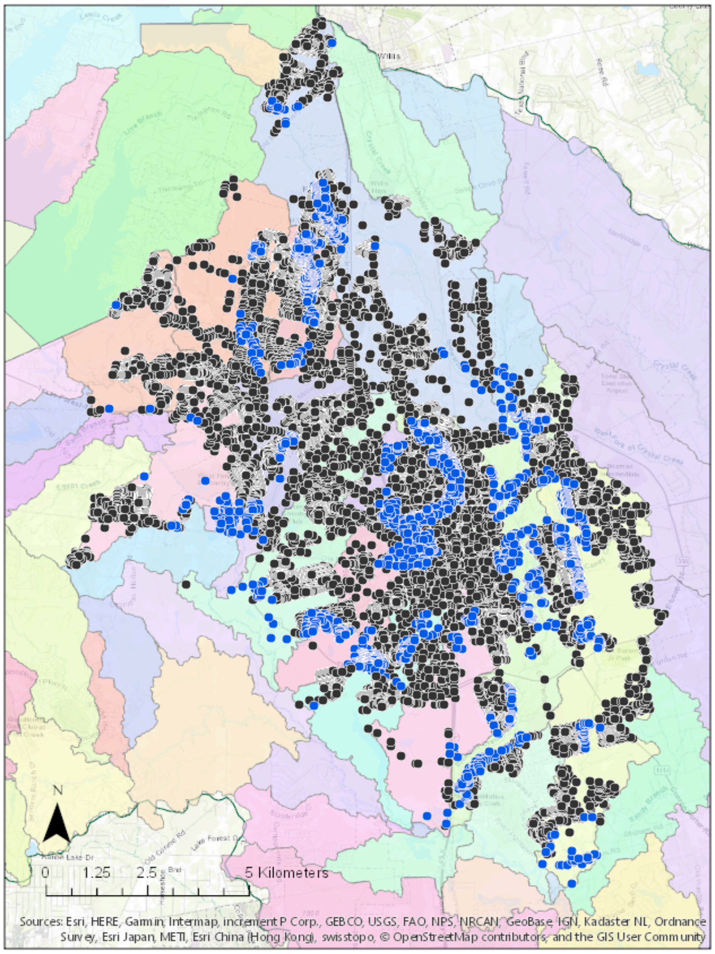


Figure 14. Flooded Address Points Scenario 1 - Conroe

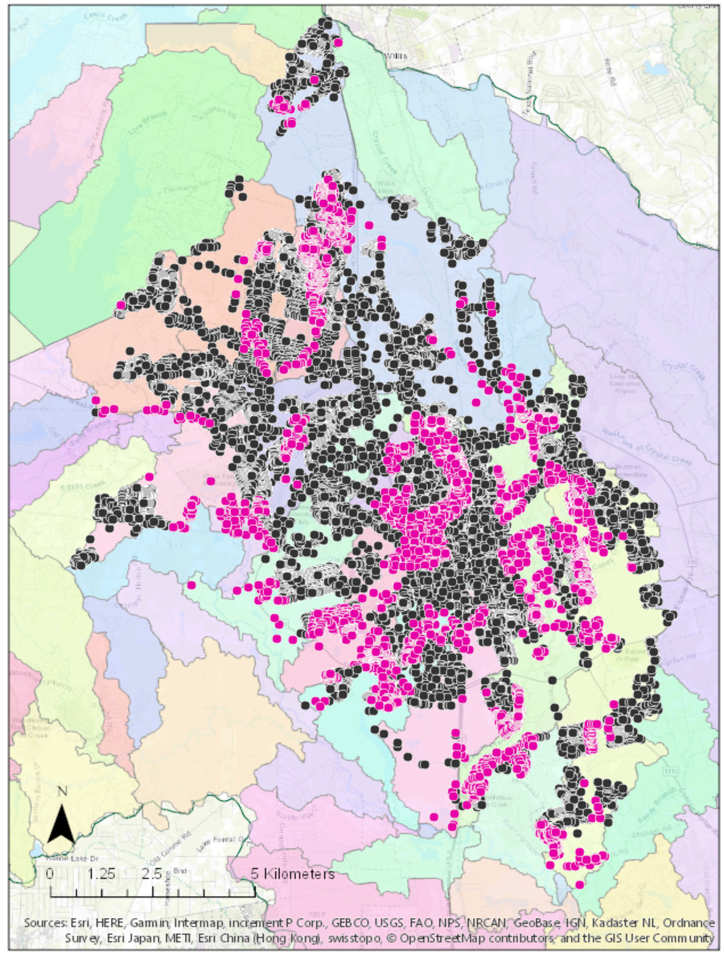


Figure 15. Flooded Address Points Scenario 2 - Conroe

As can be seen in Figure 15, there are more impacted address points in magenta (representing the no dam scenario) than there are impacted address points in blue in Figure 14 (representing the dam release after Harvey). This is most noticeable in the central area of the collection of catchpolys.

These results are very much expected as the flow rate for scenario 2 is ~1.64 times greater than the actual peak flowrate of the dam release. The change in flowrate nearly parallels the change in number of affected address points with an increase of 1.66 times more address points at risk of flooding under the conditions from scenario 2. While these statistics are important to note when considering future potential releases or floods, the distribution of inundation depths are another important result to look into. Figures 16 and 17 show the inundation depth distribution for scenario 1 and scenario 2, respectively.

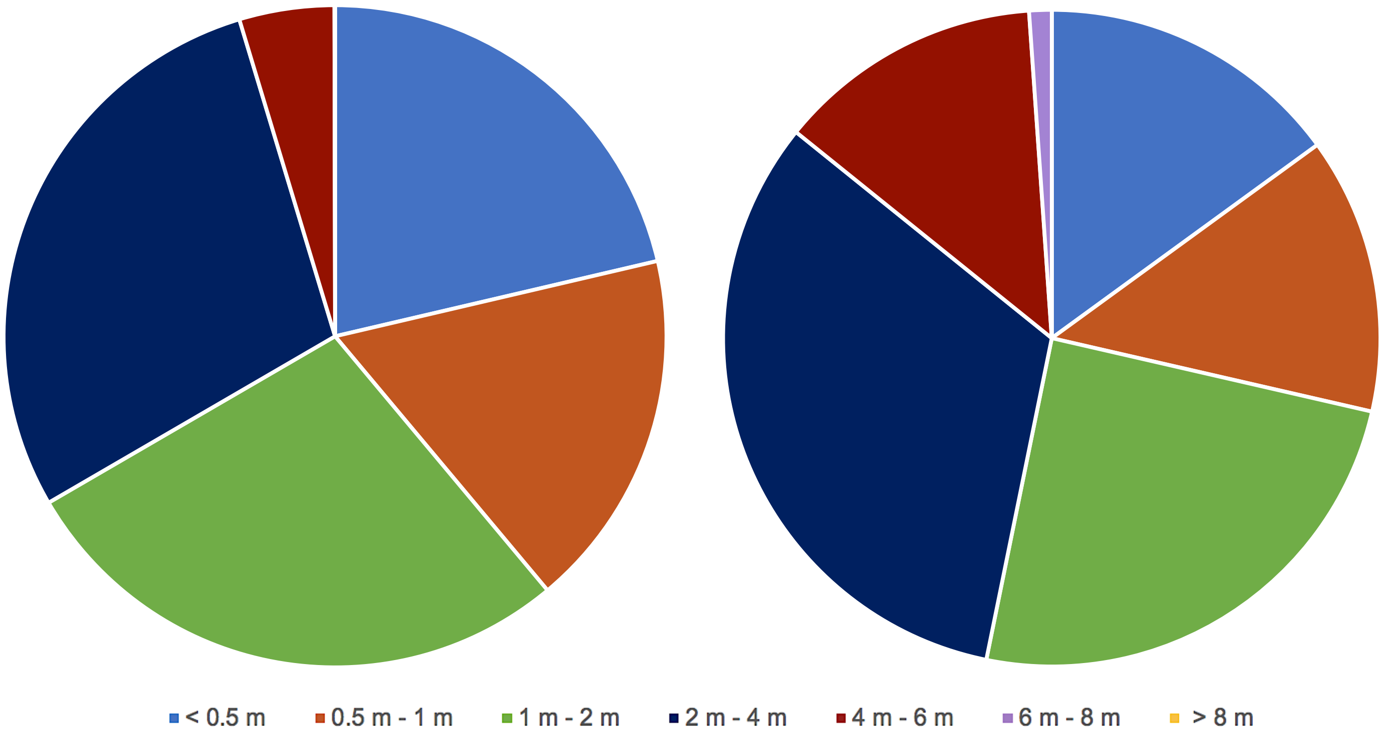


Figure 16. Inundation Depth Distribution Scenario 1 - Conroe

Figure 17. Inundation Depth Distribution Scenario 2 - Conroe

As can be seen in the pie charts, there is a much greater percentage of address points flooded more than 2 m (~ 6.5 ft) with some properties being inundated as much as 8 m (~26 ft!) under the conditions of scenario 2. Thus, in addition to more address points being subject to flooding, the no-dam scenario also increases the inundation depth of the address points, which would inflict more overall damage to the property owners.

3.2 Kingwood

The same figures were developed for the Kingwood area. The 6 catchpolys analyzed within the Kingwood focus area contained 49,639 address points. Of these, 4,126 were at risk of flooding due to the dam release and 7,790 would be at risk had the dam not existed at all. Figures 18, 19, and 20 depict the total address points, flooded address points due to the dam release, and flooded addresses due to the no-dam scenario, respectively.

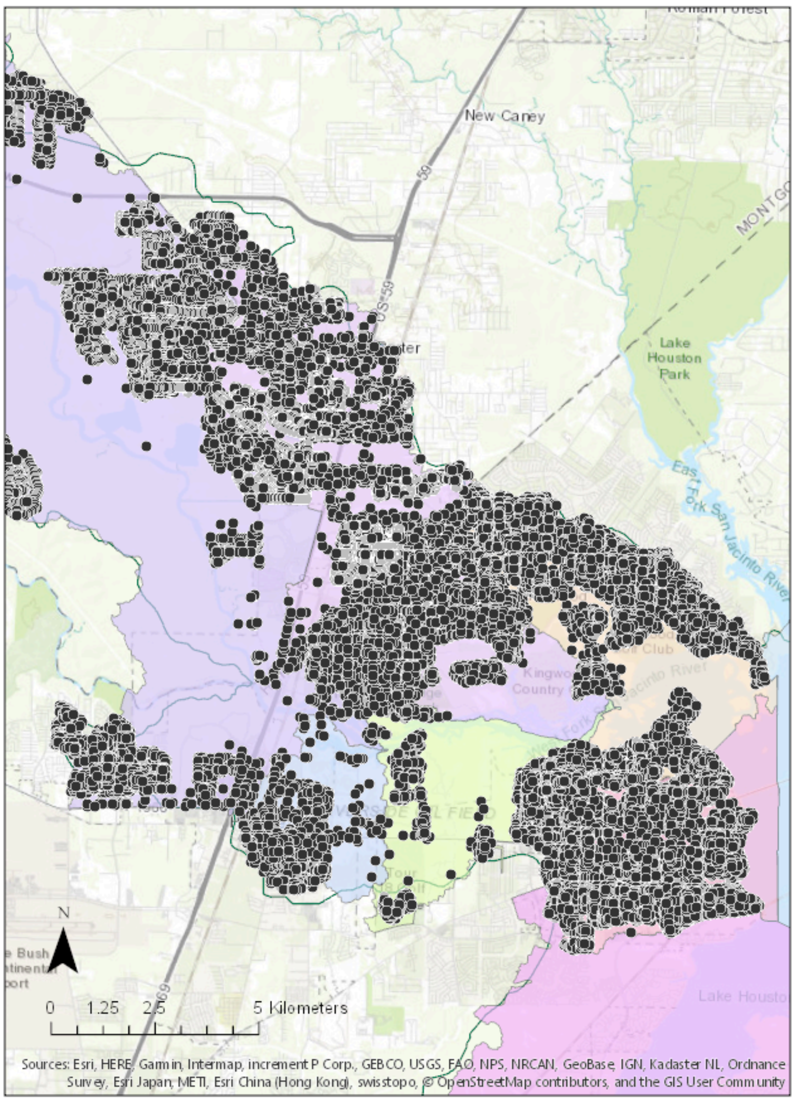


Figure 18. Total Address Points - Kingwood

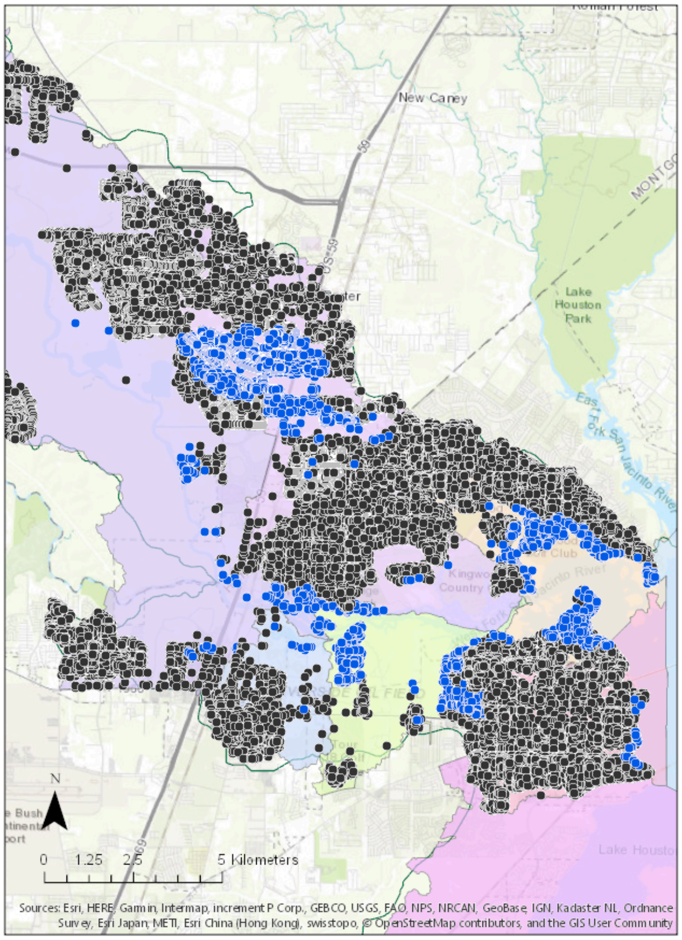


Figure 19. Flooded Address Points Scenario 1 - Kingwood

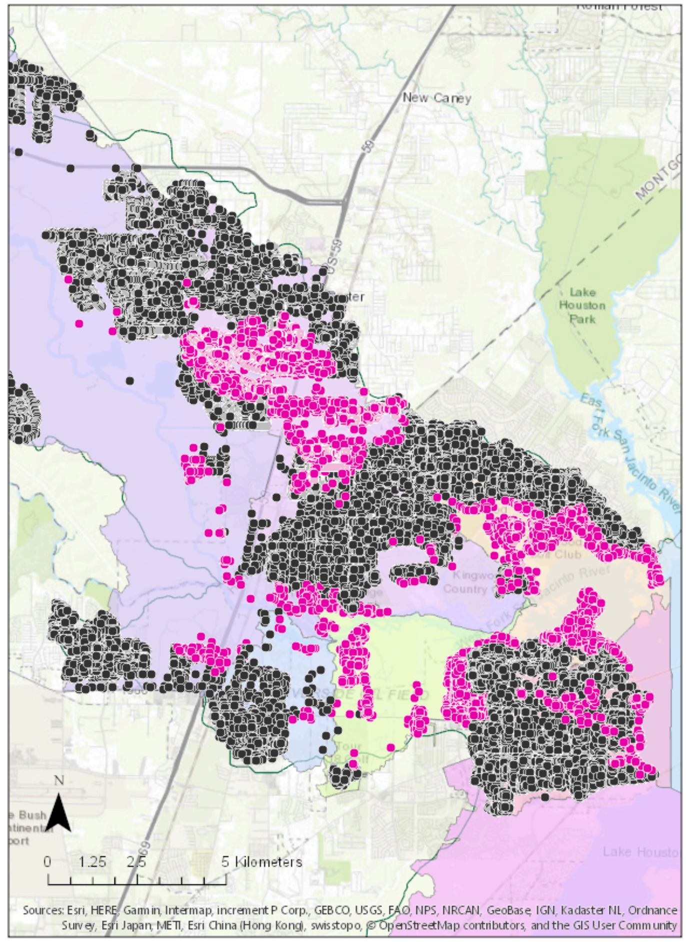


Figure 20. Flooded Address Points Scenario 2 - Kingwood

Despite consisting of only 6 catchpolys, there were more than double the number of total address points in the Kingwood focus area than in the Conroe focus area. The difference in flooded address points between the dam release and no-dam scenario is also more noticeable in this focus area. The magenta (no-dam scenario) flooded address points are more dense in the central portion of the focus area and extend more into the southeastern most portion of the area.

The distribution of inundation depths were observed for the Kingwood area as well. Figures 21 and 22 show the inundation depth distribution for scenario 1 and scenario 2, respectively.

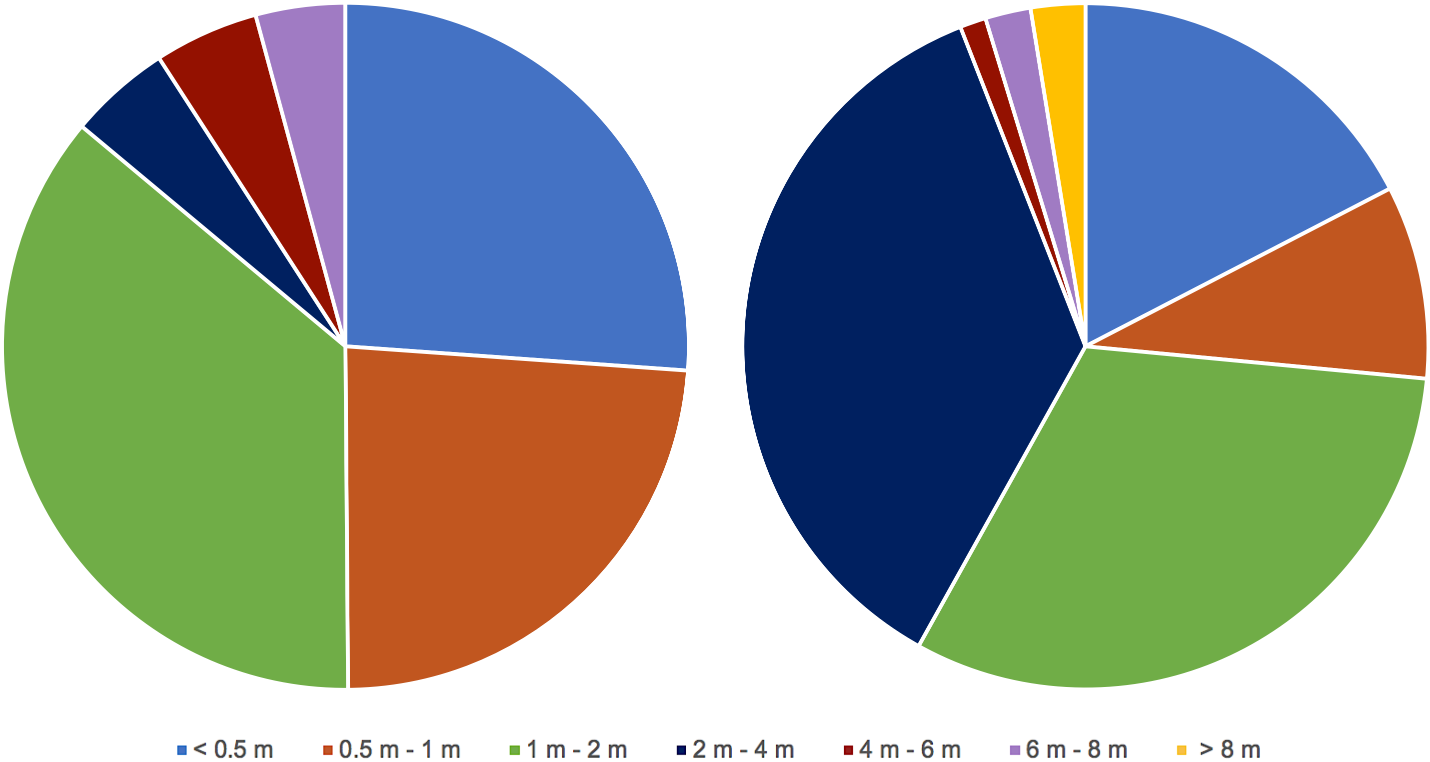


Figure 21. Inundation Depth Distribution Scenario 1 - Kingwood

Figure 22. Inundation Depth Distribution Scenario 2 - Kingwood

As compared to the Conroe area, the inundation depths in the Kingwood area for scenario 1 are more concentrated within the 2 m or less range. For both areas the distribution of inundation depths is much greater under the second scenario. However, some Kingwood area address points reach an inundation depth of more than 8 m under the second scenario. These distribution pie charts demonstrate not only the variability in address point elevation and risk, but also provide a general comprehension of the damage that can be expected during releases. Many of these inundation depths are capable of completely destroying a property and putting the residents or owners at risk if they do not evacuate. This underscores the importance of good communication and forewarning prior to a release of these magnitudes.

4.0 Conclusion

In conclusion, this study looked at two different flow scenarios, that of the actual dam release and that of the no-dam case, in two different focus areas, Conroe and Kingwood. The findings showed that almost 7,500 address points flooded exclusively due to the dam release. Had the dam not existed at all, an additional 5,800 address points would have been flooded and the damage would have been more severe with a larger portion of properties experiencing more than 2 m (roughly 6 feet) of flooding. This study demonstrated a general idea of the potential consequences of not releasing the dam waters, which could have resulted in the failure of the dam. One thing to note is that the second scenario does not account for total dam failure as there is a significant storage of water in Lake Conroe that would also have been released had the actions by SJRA resulted in the collapse of the dam. This study solely focuses on releasing the total inflow into Lake Conroe so as to provide a general scale and magnitude of the increased damage. However, this study does help underscore the importance of maintaining communication and improving warning systems between government entities and property owners during extreme storm events like Hurricane Harvey.

Additionally, this study demonstrated the effectiveness of utilizing Model Builder. While it proved to be an incredibly helpful tool when performing the same analysis on different catchpolys, it also proved to be very glitchy, causing ArcGIS to shut down multiple times in the middle of running. However, this was largely expected given the large dataset and current operating system of the modeling computer. The benefit still outweighs the risk in program shutdown given the plethora of data that is able to be analyzed by simply changing the parameter ID of interest.

4.1 Future Work

For future work, the rating curves can be refined by inputting a smaller range of experimental stage heights that will generate a more succinct rating curve for the respective catchpolys. While this may not change the final results significantly, it would yield more accurate flooded stage heights. Additionally, more catchpolys can be analyzed in both the surrounding areas and the less densely populated areas between the Conroe and Kingwood focus areas chosen for this study. This study could be extended further to look at the additional strain that the dam release placed on Lake Houston, the outlet downstream of the West Fork of the San Jacinto River.

Additionally, one of the main reasons for the lawsuits against the SJRA stem from the belief that the affected properties would not have flooded due to Hurricane Harvey rainfall, but rather flooded solely due to the dam release. By incorporating the rainfall and flooding due to other circumstances within the model, the properties that were flooded solely due to the dam release can be identified. This may yield further insight into the issue and provide a general understanding of how the properties in the area fared from Hurricane Harvey and resulting events.

5.0 References

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6.0 Appendix A

Table 2. Flooded Stage Heights for Each Catchpoly

Focus Area	Catchpoly Object ID	Flooded Stage Height (m)	
		Scenario 1 - Dam Release (79,141 cfs)	Scenario 2 - No Dam (130,000 cfs)
Conroe	499	4.014	6.280
	502	6.165	7.152
	503	5.568	6.645
	504	4.763	6.295
	506	8.031	10.123
	507	7.930	9.566
	509	6.618	7.681
	510	3.503	5.170
	511	4.313	6.147
	513	8.159	9.700
	514	4.773	6.313
	515	9.840	11.324
	516	3.321	4.848
	517	6.375	7.146
	519	2.420	3.376
	520	2.948	4.239
Kingwood	552	6.304	7.184
	555	2.596	3.645
	556	3.703	5.539
	557	8.240	10.424
	558	1.874	2.482
	559	2.520	3.653