Disentangling the Impacts of Human and Environmental Change on Catchment Response during Hurricane Harvey

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Supplementary Material

The following sections provide further information about the case study area (Section S1), the calibration (Section S2) and validation of the model (Section S3), a policy implications discussion (Section S4), and the limitations of the model (Section S5).

S.1 Description of Case Study

The Houston metropolitan region has recently been ranked as the fastest growing city in terms of population and total impervious area in the U.S., adding upwards of 3,000 people and converting nearly 2 km\textsuperscript{2} of land to development per week in recent years (Hakkenberg et al 2019, Texas State Data Center 2017). This high growth trend continues back to the early 1900s. For example, between 1910 and 1920 the city’s population doubled from just under 100,000 to 200,000 with a size of around 23 km\textsuperscript{2}. The city then began to add 200,000 to 360,000 per decade from 1940 onward until the 1970s where it began growing at nearly 1,000 people per week (Fisher 1989). The history of rapid population growth in Houston has converted large areas of open space into developed, impervious surface. Currently, the land area of the city is 1,732 km\textsuperscript{2}, about 91\% of which is developed and is ranked fourth in the nation in terms of total impervious area (Bounoua et al 2018). This process of urbanization and the expansion of impervious surfaces disrupts the natural response of the catchments by reducing infiltration and increasing surface runoff and peak flows (O’Driscoll et al 2010, Ferreira et al 2016, Mogollón et al 2016, Blessing et al 2017).

Many of the stream gauges in and around Houston indicate a positive trend in observed hydrologic flows (Supplementary Figure S1), suggesting that rapid urbanization, channel modifications, and increased precipitation due to climate change during the previous century have increased flood risk and likely contributed to the flood impacts seen during Hurricane Harvey (Berg 2018, Zhang et al 2018). Traditionally, peak discharge has been used as an indicator of increased flood risk (Hodgkins et al 2019); however, most gauges in the Harvey-impacted area have short historical records, averaging less than 40

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years, making it difficult, if not impossible, to disentangle the impacts of multiple drivers on observed discharge across time. While several previous studies have focused on the influence of changing land use during the previous fifty years on flooding in Houston (Sebastian 2016, Gori et al 2018, Kim et al 2016), to our knowledge, no studies have been undertaken aimed at directly attributing peak stream discharge during Hurricane Harvey to the combined impacts of climate and urbanization.

Supplementary Figure S1. Annual peak streamflow, in cubic meters per second, measured at (a) USGS 8074000, (b) USGS 8074500, (c) USGS 8075000, and (d) USGS 8076000. The locations of the four gauges are shown in Figure 2.

As a study location for this paper we selected the larger Buffalo-San Jacinto watershed (USGS HUC8 #12040104) which drains the majority of Houston and several incorporated and surrounding jurisdictions (Figure S2). The watershed has an area of 2,531 km², features over 2,591 km of open drainage channels, and currently houses an estimated population of 3 million (HCFCD 2018). The elevation of the watershed ranges from approximately 0-5 m above MSL at the mouth of the San Jacinto River to 60 m above Mean Sea Level (MSL) and has an average overland slope of 1.4%. With the exception of the most upstream areas, the watershed is nearly completely urbanized with developed land representing 79%, agricultural land 10%, forests 7.0% and wetlands 3.5% of the catchment area in 2018 (Anon 2019).
Supplementary Figure S2. Study area showing the location of the Buffalo Bayou – San Jacinto Watershed and the current and historical boundaries of the City of Houston relative to Galveston Bay and the Gulf of Mexico. Major tributaries feeding Buffalo Bayou: Sims, Brays, White Oak, Hunting, Vince, Greens, and Carpenters Bayous and Addicks (A) and Barker (B) Reservoirs are shown.

Buffalo Bayou serves as the primary channel for the watershed. It flows approximately 86 km eastward where it converges with the San Jacinto River 11 km above Galveston Bay. To accommodate shipping, Buffalo Bayou has been dredged up to 13 m deep as far as 25 km upstream of its convergence with the San Jacinto River. Several major tributaries feed into Buffalo Bayou including Sims, Brays, White Oak, Hunting, Vince, Greens, and Carpenters Bayous. In addition, due to flat topographic slopes in the northwestern part of the watershed and limited conveyance capacity of the neighboring Cypress Creek, significant volumes of water can spill over the watershed divide during intense rainfall events (Anon 2015, Gori et al 2018). Houston’s bayous are rainfall-fed, slow-moving, tidally-influenced, brackish streams that respond rapidly during extreme rainfall events, turning into river systems with flood depths that can exceed 10 meters. For the purpose of this study we focus on the developed areas in Buffalo Bayou and its tributaries upstream of its confluence with the San Jacinto River.

The watershed is naturally prone to flooding due to low-infiltration capacity soils and low topographic relief and is subject to intense tropical cyclones and mesoscale convective systems (MCSs). The most extreme rainfall events (>500 mm) in the region are typically associated with stalled tropical cyclones. However, there have been several MCSs which have also produced more than 500 mm of rain (Van der Wiel et al
2017). Such intense rainfall events can cause significant flash flooding across the region and several steps have been taken during the past century to mitigate flood risk. For example, in response to damaging flood events in the 1920s and 30s, two large in-line reservoirs, Addicks and Barker, were built in 1945 and 1948, respectively, to protect downtown Houston. Originally constructed approximately 20 km west of city limits, the outlets of the dams were built as open conduits, however, as development directly downstream of the dams expanded, flood gates and auxiliary spillways were later added to limit outflows from the reservoirs during extreme events. Today, the reservoirs are surrounded by substantial residential and commercial development (Sanchez-Gomez 2018). Deterioration of the dams due to aging combined with upstream development and sedimentation has decreased their original capacity and estimated flood safety levels placing them among the highest risk dams in the U.S. (United States Army Corps of Engineers n.d.)

In addition, several tributaries to Buffalo Bayou have also been re-engineered for flood control. These engineering modifications, typically in the form of channel widening, straightening, or concrete- or grass-lining, were designed to more quickly route flow downstream and increase the capacity of the channel system, thereby decreasing flooding. However, recent research has demonstrated that with increasing urbanization upstream, in some watersheds, channelization has contributed to increasing flood exposure in mid-stream and down-stream communities (Juan et al n.d.). When combined with increasing extreme rainfall due to climate change, several studies have suggested that flood risk is significantly greater than what is currently conveyed by FEMA’s flood hazard maps (Highfield et al 2013, Brody et al 2013a, 2015). For example, in a recent study of extreme precipitation events since 1880 in the Gulf Coast region, researchers found a 12% to 22% increase in the intensity of extreme precipitation events lasting three days (Van der Wiel et al 2017). This combination of a climate prone to extreme precipitation events and a city with a long history of unchecked urban expansion makes Houston uniquely vulnerable to rainfall-induced flooding and an ideal case study to examine the flood risk from the interaction of these two drivers.

S.2 Calibration and Validation of Current Conditions Model

The hydrologic model was calibrated to three recent storm events: Memorial Day Flood (May 25-26, 2015), Tax Day Flood (April 16-17, 2016), and a smaller event which occurred May 27-28, 2016. These events were chosen because they represent a range of intensity-duration events and occurred during approximately the same time period as Harvey, representing similar development and climatic conditions. The model was also validated for Hurricane Harvey (August 26-30, 2017). The spatial distribution of cumulative rainfall for the calibration events and Hurricane Harvey are shown in Figure S3.
Supplementary Figure S3. Rainfall plots showing the spatial distribution of precipitation in the watershed for the calibration and validation events. The locations of precipitation gauges are shown for the 1935 Event; radar rainfall was obtained from the Iowa State Repository of National Severe Storms Laboratory (NSSL) and used to model all other events.

The Memorial Day and Tax Day flood events caused widespread flooding across Harris County. The Memorial Day storm occurred May 25-26, 2015 and resulted in an average of 13.5 cm (5.3 in) of rain across the study area. Rainfall during the Memorial Day event was concentrated in the southwestern portion of the watershed. A maximum rainfall accumulation of 27.9 cm (11.0 in) in 12 hours was recorded in the Brays Bayou tributary (Bass et al 2016, Lindner and Schwertz 2016). It is estimated that more than 6,500 homes, 3,500 multi-family residential units, and 92 commercial buildings flooded during the Memorial Day Flood (Talbott 2015). Seven flood-related fatalities were recorded. The Tax Day flood occurred April 16-17, 2016 and resulted in an average of 19.8 cm (7.8 in) of rain across the study area. The heaviest rainfall was concentrated in the western portion of the watershed and averaged approximately 30.5-40.6 cm (12.0-16.0
in) in a 12-hr period. A maximum rainfall of 42.4 cm (16.7 in) in 12 hours was recorded in the upstream-most reaches of the watershed, equivalent to 43% of the 12-hr Probable Maximum Precipitation (PMP) (Lindner and Fitzgerald 2016). It is estimated that more than 9,800 homes, 2,700 multi-family residential units, and 50 commercial buildings flooded during the Tax Day Flood (Lindner 2016). Nine flood-related fatalities were recorded. In contrast, the May 2016 event occurred over a much smaller area. The May 2016 storm had a maximum 12-hour precipitation of 20.6 cm (8.1 in) concentrated in the northwestern portion of the watershed, causing more limited flooding of approximately 480 homes and no fatalities (Lindner 2016).

For comparison, Hurricane Harvey occurred over a 4-day period from August 26-30, 2017. Total rainfall ranged between 66.0 cm to 119.4 cm (26-47 in) across the study area, with a maximum 12-hr rainfall intensity of 53.1 cm (20.9 in) (Lindner and Fitzgerald 2018). The highest rainfall totals were observed in the southeast part of the study area however the aerial distribution of rain did not vary significantly across the study area. A maximum rainfall of 120.4 cm (47.4 inches) was recorded south of the study area at I-45 and Clear Creek, equivalent to 95% of the PMP. For the first time in history, extreme flooding necessitated releases from Addicks and Barker Reservoirs (Figure S4). It is estimated that 154,170 homes (representing 9-12% of the total number of buildings in Harris County), between 5,000-15,000 multi-family residential units, and thousands of commercial structures were flooded (Lindner and Fitzgerald 2018). Thirty-six flood-related fatalities occurred in Harris County.
Supplementary Figure S4. Stage-storage and stage-discharge relationships for Addicks (left) and Barker Reservoirs (right) based on observed data during Harvey at USGS gauges 8073100 (Addicks) and 8072600 (Barker). Vflo® requires that the curves be invertible.

Five

Twenty-two USGS stream gauges were used as calibration points (Figure S5). The gauges were chosen because of reliability of the measurements across multiple events and their spatial distribution across the watershed. A table of calibration gauges and associated characteristics is included in the Supplementary Table S1 at the end of this document. The calibration procedure focused on adjusting the soil parameters, together with the channel and overland roughness values to capture the rising limb and the peak of the observed hydrographs. The average peak flow difference and the Nash-Sutcliffe Efficiency (NSE) across the gauges was -5% and 0.85, 19% and 0.80, and -40% and 0.42 for the Memorial Day (2015), Tax Day (2016), and May 2016 storms, respectively (where negative values indicate that the model under predicted the observed discharge). The model was also validated against Hurricane Harvey. The average peak difference across all gauges was 12% and the NSE was 0.76. Although the average NSE for Harvey is lower
than the calibration storms, given the unprecedented amount of precipitation resulting from this storm and the increased uncertainty in gauge observations for such extreme flows, the authors believe these validation statistics demonstrate good model performance (Moriasi et al. 2007). Figure S6 shows hydrograph comparisons for the three largest storms and Figure S7 shows a comparison between modeled and observed peak discharge across all four storm events, indicating acceptable performance of the model.

Supplementary Figure S5. The extent of impervious cover is shown relative to the locations of the calibration gauges. Half-open circles denote the USGS gauges referenced in Figures 3 and 8; cross-hatch circles denote the gauges referenced in Figure 5.
Supplementary Figure S6. Comparison between modeled and observed hydrographs for (a) Memorial Day at USGS 8074000, (b) Memorial Day at USGS 8076000, (c) Tax Day at USGS 8074000, and (d) Harvey at USGS 8075400, modeled using the current conditions model.

Supplementary Figure S7. Comparison between modeled and observed peak discharge for Memorial Day ($R^2=0.94$), Tax Day ($R^2=0.86$), May 2016 ($R^2=0.55$), and Harvey ($R^2=0.71$), modeled using the current conditions model.

S.3 Validation of Pre-development Conditions Model
The baseline model was validated using 24-hr gauge-measured precipitation from National Climatic Data Center (NCDC) and reported peak discharge from a flood event which occurred December 6-8, 1935. During this event, approximately one-hundred business and residential blocks were inundated in downtown Houston, causing property damage of approximately $45 million in damage (adjusted for inflation) and 8 deaths (Dalrymple 1937). This event was pivotal in the decision to create of the Harris County Flood Control District (HCFCD) in 1937 and the design and construction of Addicks and Barker Dams.

The 1935 storm was reconstructed using measured hyetographs at twelve locations in the watershed as reported by the U.S. Geological Survey in Dalrymple et al. (Dalrymple 1937). Rainfall totals between 14.0 and 41.9 cm (5.5-16.5 in) were observed with the highest rainfall totals concentrated in the western portion of the watershed. The rainfall contours are shown together with the measurement locations in the Supplementary Material Figure S3. The model was validated against a single outflow hydrograph generated using rating curves based on current-meter measurements made in Buffalo Bayou at the Galveston, Harrisburg & San Antonio Railroad Eureka Cutoff Bridge (Point #1, Figure S8a) during the period between December 7-12, 1935 (NSE = 0.34). Figure S8a shows the comparison between the modeled and observed hydrograph at this location. Although the rising limb of the observed hydrograph is not well captured by the model (NSE=0.34), the peak matches very well. We calculated the difference between the observed peak discharge and the modeled peak discharge to be 1.8% (where positive values indicate that the model over predicted the observed discharge). The model results were also compared to observed peak discharge at four locations in the watershed ($R^2 = 0.96$) as shown in Figure S8b. Given limited data availability for historical events during the early 1900s, the authors find the validation results to be satisfactory. It is worth noting that several earlier floods are also reported to have caused damages in Houston in 1929, 1879 and 1854, respectively, but the observed data available from these events was insufficient for model validation.
Supplementary Figure S8. Performance of the pre-development model for the 1935 storm, showing (a) the modeled and observed flow hydrographs at Observation Point #1 and (b) the modeled and observed peak discharge at all recording gauges in 1935 ($R^2=0.96$).
S.4 Policy Implications of the Results

The significant impacts that historical changes in rainfall intensity and urbanization has had on flood risk suggests that an explicit integration of future conditions into current development decisions must be considered to achieve long term urban flood resilience. Specific precautionary flood risk management strategies can be categorized within four overarching urban flood resilience models (Su 2016): structural, financial, environmental planning, and retreat. Structural strategies that can increase flood resilience under changing climate and land use conditions are those that apply a safety margin of error. One of the most straightforward ways to accomplish this is to apply a climate change factor to existing flood control infrastructure (FCI) design criteria based on a sensitivity analyses under plausible climate change scenarios over the expected lifetime of the infrastructure. An example of this would be London’s Thames Estuary 2100 study that used a ‘high-plus-plus’ scenario to test flood defense options to the end of the 21st century (Lowe et al 2009, Environment Agency 2009).

Although safety margins can improve the capacity of FCI to withstand future increases in flood magnitudes, there also needs to be a financial incentive to motivate communities to implement such adaptive flood risk measures. Financial instruments that can be used to increase flood resilience include regulatory and incentive-based policies that promote non-structural mitigation techniques. The most comprehensive national program for incentivizing non-structural strategies in the U.S. is the National Flood Insurance Program’s (NFIP) Community Rating System (CRS), which is designed to encourage communities to exceed the NFIP’s minimum standards for floodplain management. Communities that participate in CRS program earn points for adopting specific mitigation actions in exchange for discounts on their federal flood insurance premiums. Highfield et al (2014) found that one of the most effective CRS activities for reducing insured losses is activity 430 (higher regulatory standards), which includes precautionary strategies such as the implementation of a Flood Insurance Rate Map (FIRM) created using “future-conditions hydrology” (FEMA 2013).

Integrating regional planning strategies that guides the form of the built environment at the watershed scale with FCI safety margins and non-structural financial incentives can further enhance flood resilience. Previous studies have found that land use and environmental planning that promote smart growth, spatially targeted development patterns to be one of the most effective strategies for adapting to floods (Burby et al 2000, Iwan et al 1999, Miletic 1999, Brody et al 2013b). To be effective, natural disaster management must be directly integrated with local comprehensive plans (Hawkins 2013). Jha et al (2013) refers to this as “risk-based land use planning” which requires assessing the suitability of land exposed to natural hazards
and then prioritizing urban development and infrastructure investments within the safest areas. A critical land use strategy for reducing flood risk is planning for more space for the river (European Commission 2007). Such a strategy would limit the density of development within the floodplain and preserve wetlands, both of which enhance the adaptive capacity of watersheds by buffering against future increases in peak flows and have been shown to significantly reduce the cost of floods (Brody et al 2015, Costanza et al 2008, Doubleday et al 2013).

Although controversial and expensive, managed retreat from hazardous areas through voluntary property buyouts, relocations, and land swaps for less risky areas has been promoted as a model for reducing flood risk (Stein et al 2000). This strategy is one of the most precautionary because it removes people and structures from flood-prone areas thereby eliminating the risk of property loss and economic disruption (Verchick and Johnson 2013). In the U.S., FEMA finances buyouts through the Hazard Mitigation Grant Program (HMGP). This typically happens post-disaster whereby owners of high-risk properties are offered buyouts at the structure’s pre-disaster market value, and the property is permanently restored to open space with benefit-cost ratios ranging between 2 and 5 (FEMA 2013, Rose 2007). However, buyouts are often expensive and politically contentious. Other retreat-based methods that are more affordable and less intrusive on property rights include conservation easements, overlay zones, transfer of development rights, density bonuses and special taxing districts (Highfield and Brody 2013, Bengston et al 2004, Beatley 2009).

S.5 Limitations

The results presented in this study are subject to various sources of uncertainty, which are explored below. First, the latest NLCD LULC available during this study is from 2011, meaning that portions of the watersheds that were developed after 2011 were not represented. To overcome this limitation, we calibrated the model to flood events in 2015 and 2016 by adjusting the roughness and imperviousness parameters to account for development which occurred in these areas and validated the model against Harvey (2017). The calibration and validation results indicate that this was sufficient to overcome the limitation of using an older LULC dataset. Second, in creating the pre-development LULC conditions, several assumptions were made about historical land uses in the Houston region. For example, based on aerial imagery, we assumed that much of the currently developed areas were previously used for agricultural purposes (e.g., crops, pasture) or covered by grasslands/prairie. This may have led to an underestimate in the amount of forested area and overestimated the presence of agricultural area and grasslands, which could lead to faster response times in the 1900s model (Figure 5a). Where there was uncertainty between agricultural lands and grasslands, agricultural lands were chosen since this produces a more conservative comparison between the
1900 and 2017 peak discharge. We also assume that, in general, soil characteristics have not changed significantly across time, but acknowledge that the root structures of certain vegetative types (e.g., prairie) may have enhanced infiltration when compared against today’s land cover (Anon 2015) and that changing land use has likely also contributed to soil compaction (Tessler et al 2015, Sayers et al 2013, O’Connell et al 2007). Third, the effect of development policies, such as retention or detention requirements, were not considered in the model. Recent research suggests that existing detention policies in the region are not sufficient to offset the impacts of development (Fisher 1989), justifying the approach taken in this study.

In this paper, we focus on extreme precipitation as the primary cause of flooding during Harvey; however, we also acknowledge that several other factors may have contributed to the observed flooding. First, we did not consider the effects of climate-driven sea level rise in Galveston Bay. Sea level rise can exacerbate both high tides and storm surge, potentially contributing to the coastal impacts seen during Harvey, as well as create a backwater effect in downstream areas exacerbating the interactions between urban runoff and coastal storm surge (Sebastian 2016). The effects of localized subsidence on changing flood risks in the Houston area was not considered; despite the fact that oil and gas extraction and groundwater withdrawals led to significant subsidence during the first half of the 20th century and resulted in the creation of the Houston-Galveston Subsidence District (HGSD) in 1975. Subsidence has since slowed considerably, however, subsidence during the mid-20th century has likely led to different watershed boundaries than were present in the 1900s. For the purpose of this study, the flow direction network was held constant across all model scenarios, however, in future research, the impacts of both sea level rise and subsidence on watershed response merit further analysis. Finally, recent research suggests that the impact of urbanization on the full catchment response may be even greater than estimated in this analysis. For example, in Zhang et al. (Zhang et al 2018), researchers found that urbanization contributed to even higher precipitation totals than when considering impacts of anthropogenic climate change alone, suggesting that the impact of urbanization on flooding may be even greater than illustrated in this study. This should be further explored in future research.

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Supplementary Table S1

Supplementary Table S1. Description of the USGS gauges shown in Figure 2. The total contributing area and start and end dates of the available streamflow record at each gauge is shown. A “*” is used to denote the gauges used for model calibration.

| Watershed       | Site No. | Station Name                                      | Area (km²) | Start Date | End Date |
|-----------------|----------|---------------------------------------------------|------------|------------|----------|
| Cypress Creek   | 8068700  | Cypress Ck at Sharp Rd nr Hockley, TX             | 209.0      | 1979       | 2017     |
|                 | 8068720  | * Cypress Ck at Katy-Hockley Rd nr Hockley, TX    | 284.9      | 1976       | 2017     |
|                 | 8068740  | * Cypress Ck at House-Hahl Rd nr Cypress, TX      | 339.3      | 1905       | 2017     |
|                 | 8068750  | Cypress Ck nr Cypress, TX                         | 357.4      |            |          |
|                 | 8074020  | * Whiteoak Bayou at Alabonson Rd, Houston, TX     | 89.4       | 1984       | 2017     |
| Cole Creek      | 8074100  | Cole Ck at Guhn Rd, Houston, TX                   | 18.3       | 1965       | 1972     |
|                 | 8074150  | * Cole Ck at Deihl Rd, Houston, TX                | 19.4       | 1964       | 2017     |
| Brickhouse Gully| 8074250  | * Brickhouse Gully at Costa Rica St, Houston, TX  | 29.5       | 1965       | 2017     |
|                 | 8074500  | * Whiteoak Bayou at Houston, TX                   | 246.3      | 1929       | 2017     |
| Little Whiteoak | 8074540  | * Little Whiteoak Bayou at Trimble St, Houston, TX| 46.9       | 1981       | 2017     |
|                 | 8074550  | Little Whiteoak Bayou at Houston, TX              | 54.1       |            |          |
|                 | 8074598  | Whiteoak Bayou at Main St, Houston, TX            | 328.9      | 1993       | 2018     |
| Hunting Bayou   | 8075760  | Hunting Bayou at Falls St, Houston, TX            | 7.1        | 1965       | 1984     |
|                 | 8075763  | Hunting Bayou at Hoffman St, Houston, TX          | 18.7       | 2007       | 2017     |
|                 | 8075770  | * Hunting Bayou at IH 610, Houston, TX            | 41.7       | 1964       | 2017     |
| Greens Bayou    | 8075780  | * Greens Bayou at Cutten Rd nr Houston, TX        | 22.4       | 1965       | 2017     |
|                 | 8075900  | * Greens Bayou nr US Hwy 75 nr Houston, TX        | 94.8       | 1966       | 2017     |
|                 | 8076000  | * Greens Bayou nr Houston, TX                     | 177.9      | 1953       | 2017     |
| Garners Bayou   | 8076180  | * Garners Bayou nr Humble, TX                     | 80.3       | 1987       | 2017     |
| Halls Bayou     | 8076200  | Halls Bayou at Deertrail St, Houston, TX          | 22.5       | 1965       | 1983     |
| USGS Station | Location | Discharge (cfs) | Year Flooded | Year | Year Flooded | Year |
|--------------|----------|----------------|--------------|-----|--------------|-----|
| 8076500      | Halls Bayou at Houston, TX | 74.3 | 1953 | 2017 |
| 8076530      | Halls Bayou at Parker Rd, Houston, TX | 89.9 | | |
| 8076700      | Greens Bayou at Ley Rd, Houston, TX | 471.4 | 1972 | 2017 |
| **Langham Creek** | **Bear Creek** | **Mayde Creek** | **Addicks Reservoir** | **Barker Reservoir** | **Buffalo Bayou** | **Bray's Bayou** | **Keagan's Bayou** | **Willow Waterhole** |
| 8072760      | Langham Ck at W Little York Rd nr Addicks, TX | 63.7 | 1978 | 2017 |
| 8072800      | Langham Ck nr Addicks, TX | 126.7 | 1974 | 2017 |
| 8072730      | Bear Ck nr Barker, TX | 55.7 | 1978 | 2017 |
| 8072680      | S Mayde Ck at Heathergold Dr nr Addicks, TX | 79.3 | 2016 | 2017 |
| 8072700      | S Mayde Ck nr Addicks, TX | 83.7 | 1974 | 2015 |
| 8073100      | Langham Ck at Addicks Res Outflow nr Addicks, TX | 352.2 | 2014 | 2017 |
| 8072600      | Buffalo Bayou at State Hwy 6 nr Addicks, TX | 375.5 | 2011 | 2017 |
| 8073500      | * Buffalo Bayou nr Addicks, TX | 717.4 | 1945 | 2017 |
| 8073600      | * Buffalo Bayou at W Belt Dr, Houston, TX | 751.1 | 1972 | 2017 |
| 8073700      | * Buffalo Bayou at Piney Point, TX | 774.4 | 1964 | 2017 |
| 8074000      | * Buffalo Bayou at Houston, TX | 870.2 | 1929 | 2017 |
| 8074600      | Buffalo Bayou at Main St, Houston, TX | 878.0 | 1993 | 1994 |
| 8074610      | Buffalo Bayou at McKee St, Houston, TX | 1175.9 | 1993 | 1998 |
| 8074620      | Buffalo Bayou at Hirsch St, Houston, TX | 1183.6 | | |
| 8074630      | Buffalo Bayou at Lockwood Dr, Houston, TX | 1191.4 | | |
| 8074700      | Buffalo Bayou at 69th St, Houston, TX | 1199.2 | | |
| 8074710      | Buffalo Bayou at Turning Basin, Houston, TX | 1204.3 | 1987 | 2017 |
| 8074750      | Brays Bayou at Addicks-Clodine Rd, Houston, TX | 2.3 | | |
| 8074760      | Brays Bayou at Alief, TX | 38.8 | 1977 | 2017 |
| 8074780      | Keegans Bayou at Keegan Rd nr Houston, TX | 22.4 | 1964 | 2002 |
| 8074800      | * Keegans Bayou at Roark Rd nr Houston, TX | 32.9 | 1964 | 2017 |
| 8074810      | * Brays Bayou at Gessner Dr, Houston, TX | 136.0 | 1977 | 2017 |
| 8074900      | Willow Waterhole Br at Landsdowne, Houston, TX | 9.9 | 1964 | 1972 |

* indicates a recorded flood with no extent of water.
| Code     | Description                           | Distance | Year | Time |
|----------|---------------------------------------|----------|------|------|
| 8075000  | * Brays Bayou at Houston, TX          | 245.8    | 1900 | 2017 |
| 8075100  | Brays Bayou at Scott St, Houston, TX  | 274.5    |      |      |
| 8075110  | * Brays Bayou at MLK Jr Blvd, Houston, TX | 349.6 | 2006 | 2017 |
| 8075120  | Brays Bayou at Lidstone Ave, Houston, TX | 352.2 |      |      |
| 8075300  | Sims Bayou at Carlsbad St, Houston, TX | 9.9     | 1965 | 1972 |
| 8075400  | * Sims Bayou at Hiram Clarke St, Houston, TX | 52.3 | 1964 | 2017 |
| 8075470  | Sims Bayou at MLK Blvd, Houston, TX   | 125.4    |      |      |
| 8075500  | Sims Bayou at Houston, TX             | 163.2    | 1953 | 2017 |