

Houston Solutions Lab 2017 Project Report

COUPLED FLOOD ALERT SYSTEM AND INFRASTRUCTURE RISK MODELING FOR WHITE OAK BAYOU

Philip Bedient and Jamie Padgett



History of Flooding on White Oak Bayou

The Flood Alert System (FAS) for White Oak (WO) Bayou (FAS-WO) was suggested by the SSPEED Center due to the long history of flooding in this important watershed area. The graph below clearly shows how peak annual flows have increased since the 1960s, and with six major floods since 1990, the region is very prone to flood damage. The 1992 flood, TS Allison in 2001, and Harvey in 2017 are the three top floods of record. The FAS-WO can provide lead-time and early warnings for city leaders, emergency personnel, and impacted citizens as Houston continues to deal with major flood response and mitigation in the years ahead. Monies are being provided for mitigation from the recent bond election in Harris C.

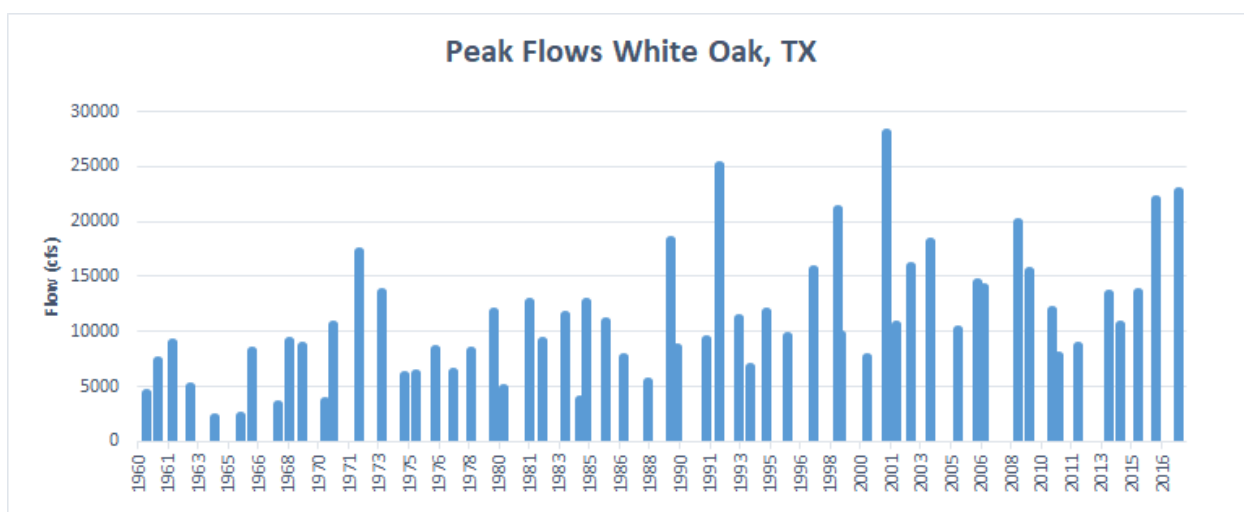


Figure 1a FAS White Oak (WO) Layout

Functions of FAS of White Oak Bayou (FAS-WO)

The Flood Alert System (FAS) for White Oak (WO) Bayou (FAS-WO) has been developed by the SSPEED Center at Rice University and currently hosted at Amazon Web Services with an IP address of: <http://34.217.98.243:8080/map>. This state-of-the art of the FAS-WO system can (A) display rainfall intensity for all the sub-catchments of the White Oak Bayou watershed in real time, and (B) forecast the flood inundation maps over the White Oak Bayou watershed using NEXRAD radar rainfall data provided by Vieux & Associates, Inc. – one of the best radar rainfall data providers in the nation. The system is based on FAS4 funded by TMC for Brays Bayou.

FAS-WO Enabled by Google Maps

Given the general popularity of Google Maps – a web mapping service application and technology provided by Google – the FAS-WO system displays the FPML within the Google Maps frame. The FAS-WO enabled by the Google Maps serves as the main platform to provide flood warnings and monitor flood risks. **Figure 1b** demonstrates a map depicting the White Oak Bayou watershed within Google Maps on the FAS-WO website. This map shows outlines of White Oak Bayou (red) and its sub-basins (black).

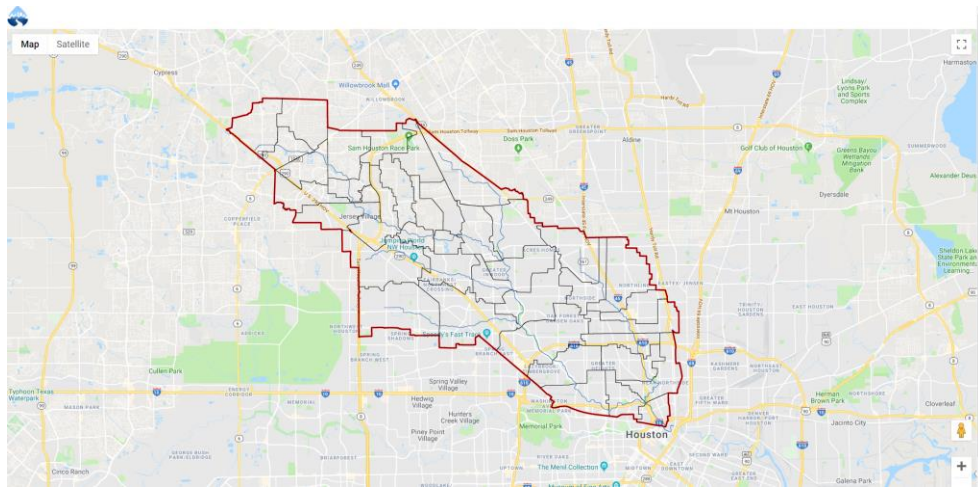


Figure 1b FAS White Oak (WO) Layout

Real-time Radar Rainfall for FAS-WO

When rainfall occurs in the watershed, the FAS-WO algorithm determines a color for each sub-basin according to a rainfall estimate in every 15 minutes. Rainfall estimates are updated whenever the FAS-WO server receives new data. Showing colored rainfall information in Google Maps enables emergency personnel to better understand weather conditions during any events. The FAS-WO system (the website) uses the same algorithm to display rainfall intensity for each sub-catchment as the one used in FAS4 for Brays Bayou as shown in **Figure 2**. The rainfall information is updated every 15 minutes.

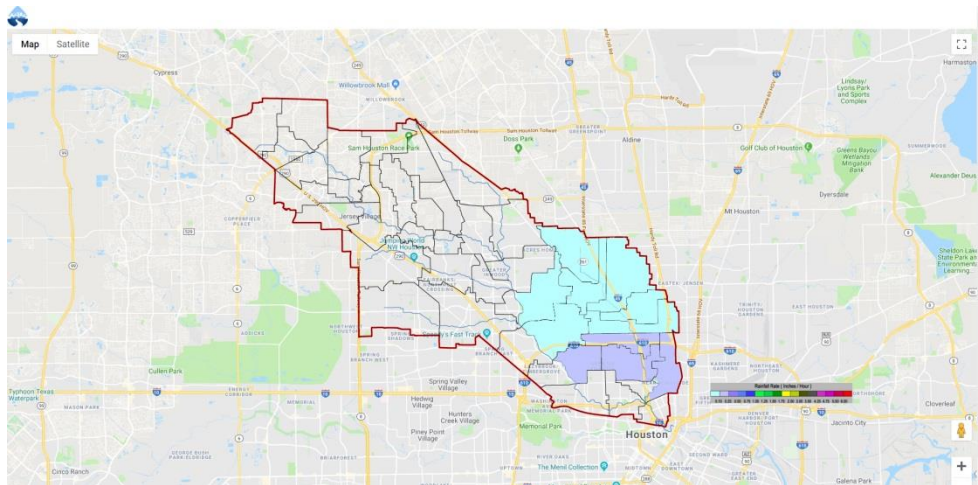


Figure 2 Rainfall Information Displayed on FAS-WO

Floodplain Map Library (FPML) for FAS-WO

Due to the demand for mapped inundation information by emergency personnel, Fang et al. (2008) developed a hydraulic prediction tool – Floodplain Map Library (FPML) that provides visual images of

flooding conditions as storms progress. The FPML system consists of the maps that were pre-delineated based on various rainfall totals incorporating frequencies, durations, and spatial variations. Each possible scenario has a unique total rainfall value. The rainfall totals of floodplain maps range from 4 inches to 14 inches over the upper and lower watershed areas, representing an envelop of flooding probabilities between 10-year and 100-year frequencies. These maps allow emergency personnel to know at a glance where flooding will be most severe and which roads are most likely to be inundated. This prediction feature is useful to critical transportation infrastructure because it enables them to understand inundation conditions and initiate appropriate evacuation strategies at many levels to deal with emerging issues.

FAS-WO is equipped with a newly developed FPML for the White Oak Bayou watershed. Corresponding flood inundation maps can be called out based on 15-minute rainfall estimates. A robust selection algorithm was scripted in Python and works in the following logic:

- 1) The 15-minute radar rainfall information is consolidated into two mean areal precipitation (MAP) values in real time for the upstream and downstream sections of White Oak Bayou (U for upstream and D for downstream);
- 2) The consolidated rainfall information (MAP) is accumulated into three past durations: 3, 6, and 12 hours; (useful time intervals based on results from FAS4 over Brays Bayou)
- 3) The algorithm compares the cumulative MAP values for the upstream U and downstream D sections against various threshold values: (i.e., 4, 8, and 12 inches);
- 4) Once any threshold value is reached for the upstream and downstream sections, an appropriate flood plain map is called up from the pre-delineated Floodplain Map Library (FPML) and displayed on the Google Maps platform;
- 5) The FPML currently contains 32 floodplain maps that were generated from hydrologic and hydraulic simulations using the Tropical Storm Allison Recovery Project (TSARP) models in advance.

Figure 3 shows one floodplain map of the FAS-WO FPML under a scenario of 8 inches of rainfall over 6 hours and 14 inches rainfall over 12 hours for the U and D regions, respectively.

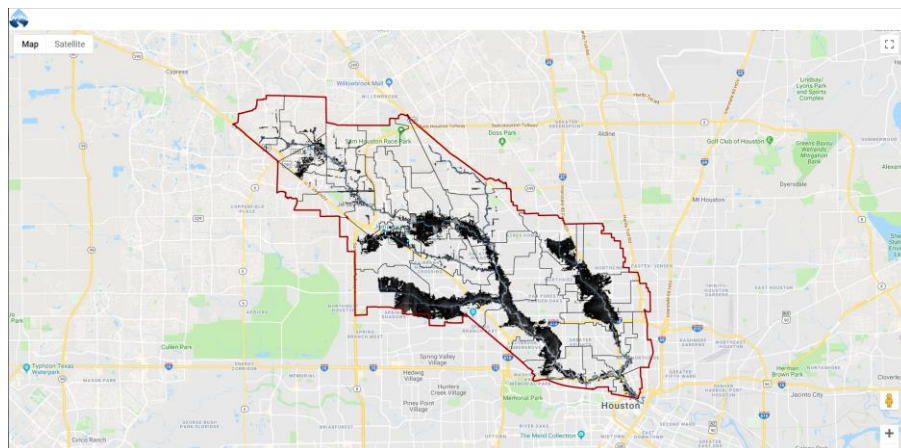


Figure 3 Floodplain Displayed on the FAS-WO

Two USGS stream gauges (8074020 and 8074500) are selected as observation points for the FAS-WO: USGS (8074020) is located at Alabonson Rd., and USGS (8074500) is located at the most downstream point near Heights Blvd in WOB. The FAS-WO can retrieve the real-time water surface elevation for these two locations and provide the associated flood risk based the following criteria:

- The warning message is displayed on the FAS-WO as shown in Figure 4.

Not only does the floodplain map library system have the capability of zooming into certain hotspots and major transportation routes that repeatedly suffer flooding in the past but also it demonstrates the flood risks at the selected critical transportation locations across White Oak Bayou (**Figure 5**). The interactive web site will provide end users with an understanding of dynamic flood response allowing emergency personnel to begin flood preparations with as much lead time as possible.

Beyond the web deployed FAS, this project provided the foundation for integrating transportation accessibility with flood alert. Specifically, a new Access to Critical Facilities (ACF) model together with the FAS forms an expanded framework (FAS-ACF) for improving situational awareness in flood events and understanding access to critical facilities. A network and spatial analysis toolbox was written in Python using modules from NetworkX and ArcGIS forming the core of the ACF model. The ACF model evaluates

Accessibility Measures (AMs) integrating data from inundation maps, road network models, spatial location of critical facilities, and census data. Inundation maps from the FPML are used to inform the ACF model and generate an Accessibility Measures Library (AML). The AML consists of maps quantifying accessibility measures like road link condition, connectivity between critical facilities and census tracts, and travel time for emergency response. Detailed descriptions of accessibility measures used in the present study are given in Table 1.

For the White Oak Bayou application (FAS-ACF-WO), a library of accessibility measures was generated for each of the flood plain maps. In total five example AMs were evaluated for each FPM resulting in a set of 160 maps in the AML. The five measures evaluated include: 1) road link status; 2) connectivity loss to hospitals; 3) connectivity loss to national shelters; 4) connectivity loss to fire stations; 5) travel time to fire stations. During a storm event, real-time radar and gauge data will be used to identify the pertinent scenario from FPML and the corresponding AML. For example, Figures 5a and 5b illustrate the average connectivity loss and travel time between fire stations and census tracts, respectively. Such information can inform pre-event planning regarding siting of facilities or infrastructure risk mitigation efforts, as well as emergency response activities by providing estimates of accessibility impacts.

Table 1 Descriptions of Accessibility Measures (AMs) and their potential applications

AMs	Description	Potential applications
Road link status	Provides information on the operability status of a road link. Road are either closed due to flood inundation or open to traffic.	<ul style="list-style-type: none"> - Identify routes for emergency response - Secure critical roadways for long-term accessibility
Connectivity loss (CL)	Measures the efficiency reduction of connectivity. CL ratio varies from 0 to 1, with 1 being completely inaccessible and 0 being no connectivity loss due to flood.	<ul style="list-style-type: none"> - Identify spatial distribution of vulnerable populations and prioritize emergency response - Optimize the spatial distribution of critical facilities like hospitals and fire stations
Travel time	The best estimate of the travel time from a critical facilities like fire stations to a census tracts.	<ul style="list-style-type: none"> - Evaluate the performance and efficacy of emergency response operations

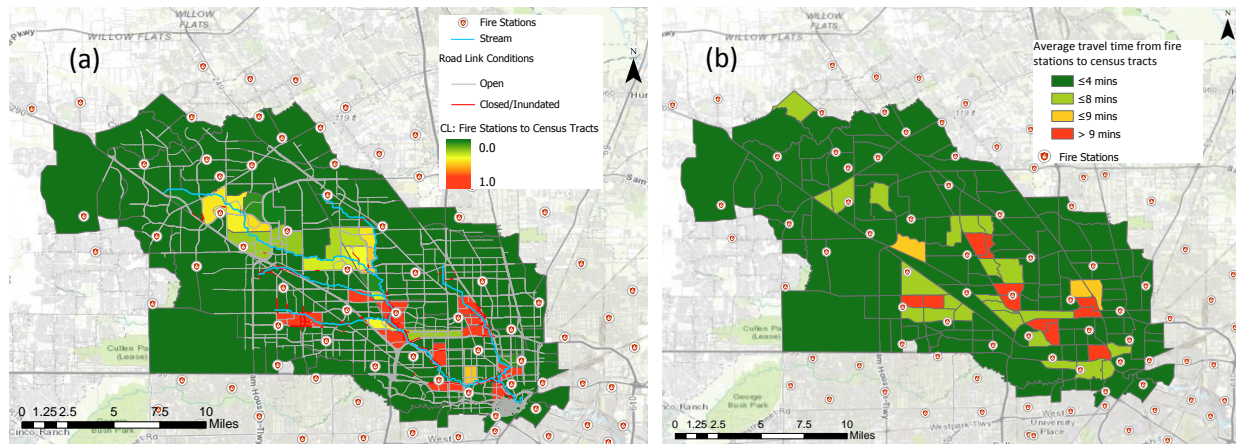


Figure 5 a) Average CL between fire stations and census tracts and b) average travel time between fire stations and census tracts for a select scenario from FPML.

Conclusion and Future Work

The FAS-WO has been developed and will be connected into an active FAS web site in the next few months for testing against actual storms. The FAS-WO can provide lead-time and early warnings for city leaders, emergency personnel, and impacted citizens as Houston continues to deal with major flood response and mitigation in the years ahead. The system consists of a series of floodplain maps (32 GIS maps) that link to real time radar rainfall and are displayed as a function of time as a storm passes through White Oak watershed. The system is built within the Google Maps technology and has full functionality for zooming in at the neighborhood level to see details of the flood inundation. The method used here is based on the FAS4 for Brays Bayou (with over 20 years of history) and can be easily expanded to other watersheds in the Houston area to assist in flood warning and flood damage response.

The FAS-ACF-WO framework can be used to evaluate, in near real-time, system level performance such as connectivity between critical facilities and census tracts, travel time for emergency response, and operability of major roads. Thus this project provided for key algorithm development and model integration with a path toward future practical implementation. One next step would be implementation of the integrated FAS-ACF-WO model in the web application. Although demonstrated on a single watershed, the methodology developed in this study can be extended to other bayous across the Houston region. Further, the framework could be tailored to address specific stakeholder interests like the city, Texas Medical Center, fire departments, or other agencies. Furthermore, the model could be enhanced by considering additional factors such as debris impacts on roadway functionality and uncertainty in hazard and infrastructure performance.