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Buffalo Bayou Watershed Near Katy Flood Analysis

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Abstract

Buffalo Bayou, originating near Katy, Texas, is a vital watercourse within the Houston metropolitan area, traversing diverse urban, suburban, and rural landscapes. This paper investigates the flood mechanisms impacting the Buffalo Bayou watershed, focusing on significant flood events and various flood mitigation methods. Key historical floods, such as those caused by Tropical Storm Allison (2001), the Memorial Day Flood (2015), the Tax Day Flood (2016), and Hurricane Harvey (2017), underscore the region's vulnerability to intense rainfall and storm systems. By examining a 20-year period of daily streamflow and climate data, this study employs the bucket model to simulate long-term discharge and predict flood occurrences. The results highlight the critical need for effective flood mitigation strategies, including the use of reservoirs, green infrastructure, and infrastructure improvements. The study aims to enhance flood management practices and community resilience within the Buffalo Bayou watershed, offering insights into the dynamic interplay between natural hydrological processes and human interventions.

Keywords: Buffalo Bayou, environmental protection, sustainable development

1. Introduction

Buffalo Bayou, originating near Katy, Texas, is a critical watercourse within the Houston metropolitan area, stretching approximately 53 miles before joining the San Jacinto River. The bayou passes through around 447 square miles of diverse landscapes, including urban, suburban, and rural areas, contributing to its complex hydrological patterns. This paper investigates the flood mechanisms affecting the Buffalo Bayou watershed, focusing on significant flood events and examining various flood mitigation methods employed to manage and reduce flood risks.

Buffalo Bayou has experienced numerous significant flood events driven by intense rainfall and storm systems. The region's climate, marked by tropical storms and hurricanes, frequently leads to substantial precipitation within short timeframes, overwhelming the natural and built drainage systems. This results in the bayou overflowing its banks and inundating adjacent areas. Notable floods in the 21st century include:

- Tropical Storm Allison (2001): This event caused extensive flooding throughout Houston, with Buffalo Bayou experiencing substantial overflow. Over five days, Allison dropped more than 35 inches of rain in some areas, leading to catastrophic flooding. The resulting damage was widespread, with an estimated $5 billion in

economic losses, more than 70,000 homes flooded, and 23 lives lost (National Weather Service, 2001).

- Memorial Day Flood (2015): Driven by intense rainfall, this severe flood event resulted in major impacts on the Buffalo Bayou watershed. Over 10 inches of rain fell in Houston overnight, causing Buffalo Bayou and its tributaries to overflow. The floodwaters inundated homes, roads, and businesses, resulting in eight deaths and over $450 million in damages (National Weather Service, 2015).
- Tax Day Flood (2016): Characterized by heavy rainfall, this flood event led to significant peak flows and widespread inundation. The storm dropped up to 17 inches of rain in a 24-hour period, leading to severe flooding along Buffalo Bayou. The flood caused more than $2.7 billion in damages, affecting thousands of homes and businesses (National Weather Service, 2016).
- Hurricane Harvey (2017): One of the most catastrophic floods in Houston's history, Hurricane Harvey brought unprecedented rainfall, causing record-high water levels and severe flooding across the watershed. Harvey dumped more than 50 inches of rain in some areas over several days, affecting over 300,000 structures and causing total economic losses estimated at around $125 billion (National Weather Service, 2017).

These events illustrate the recurring nature of flooding in the Buffalo Bayou watershed and highlight the critical need for effective flood mitigation strategies. The paper further explores the interaction between the bayou's hydrological characteristics and human interventions, providing insights into potential improvements in flood management to enhance community resilience.

2. Study Area and Methodology

This study investigates the flood mechanisms in the Buffalo Bayou watershed near Katy, Texas, identified by USGS ID 08072300. The watershed covers an area of 63.3 square miles, featuring flat to gently rolling terrain with elevations ranging from about 100 feet near its origin to 50 feet as it approaches downtown Houston. The gaging station is located at latitude 29°45'45" and longitude 95°45'58". This region's topography, combined with heavy rainfall patterns, makes it particularly susceptible to flooding. The USGS monitoring site at Buffalo Bayou near Katy provides continuous streamflow data, which is essential for understanding the hydrological behavior and flood risks of the watershed (USGS, 2021).

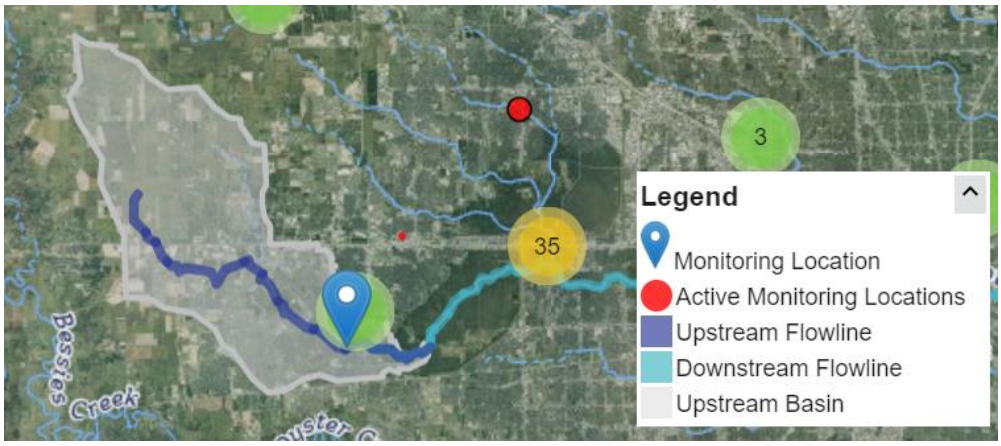

Figure 1. Flowline and gauge of the Buffalo Bayou watershed near Katy

Buffalo Bayou watershed near Katy experiences a humid subtropical climate characterized by hot, humid summers and mild winters, with significant rainfall throughout the year. Katy receives an average annual rainfall of approximately 45 inches, distributed throughout the year, with the wettest months typically being May and June, and a secondary peak in September. Heavy rain events, often associated with thunderstorms or tropical systems, can lead to rapid water accumulation and increased flood risks (NOAA, 2020).

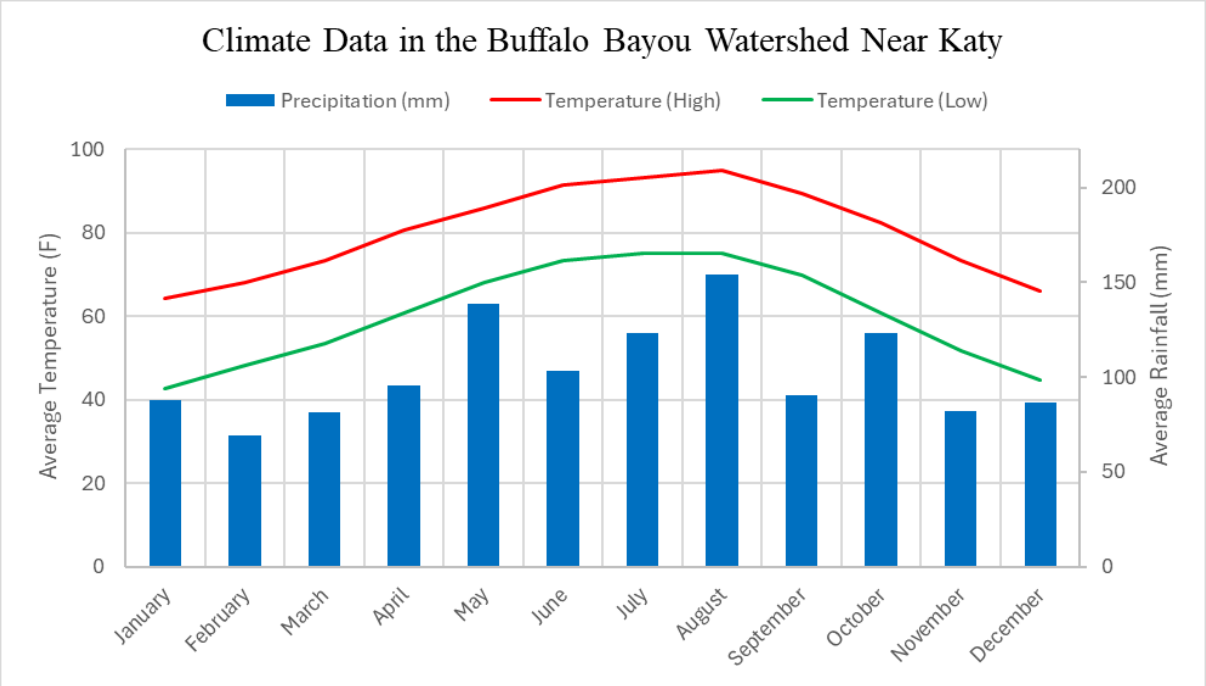

Figure 2. Climate data in the Buffalo Bayou Watershed near Katy, TX

This study selects 20-year gap-free daily streamflow and climate data from 2000 to 2019, allowing a maximum of five missing data days per year. Daily mean streamflow records are sourced from the U.S. Geological Survey (USGS) National Water Information System (NWIS), while daily precipitation data are obtained from the National Oceanic and Atmospheric Administration (NOAA) (USGS, 2021; NOAA, 2020).

The land developed level is also investigated from land use and land cover (LULC) datasets in 2001 and 2019. According to the National Land Cover Database (NLCD) classification, developed land in a catchment is categorized into four groups: developed open space, developed low-intensity areas, developed medium-intensity areas, and developed high-intensity areas (Homer et al., 2015). Katy, Texas, exhibits a diverse mix of land cover types that reflect its dynamic landscape.

The predominant land cover in Katy is "Planted/Cultivated" land, which accounts for 61.2% of the area, highlighting the region's agricultural roots and ongoing cultivation activities. Developed land, encompassing residential, commercial, and infrastructural developments, constitutes 35.3% of the area, indicating significant urban expansion. Forested areas make up a smaller portion at 0.64%, complemented by minimal coverage of shrubland (0.19%) and herbaceous land (0.46%), which contribute to the region's biodiversity. Water bodies cover 0.59% of Katy, providing essential resources for both the ecosystem and human activities. Additionally, wetlands, which make up 1.25% of the area, play a crucial role in flood control and ecological balance. The barren land is a negligible 0.32%, indicating limited non-vegetative surfaces. This varied land cover underscores the interplay between natural landscapes and human development in shaping Katy's environmental and socio-economic framework.

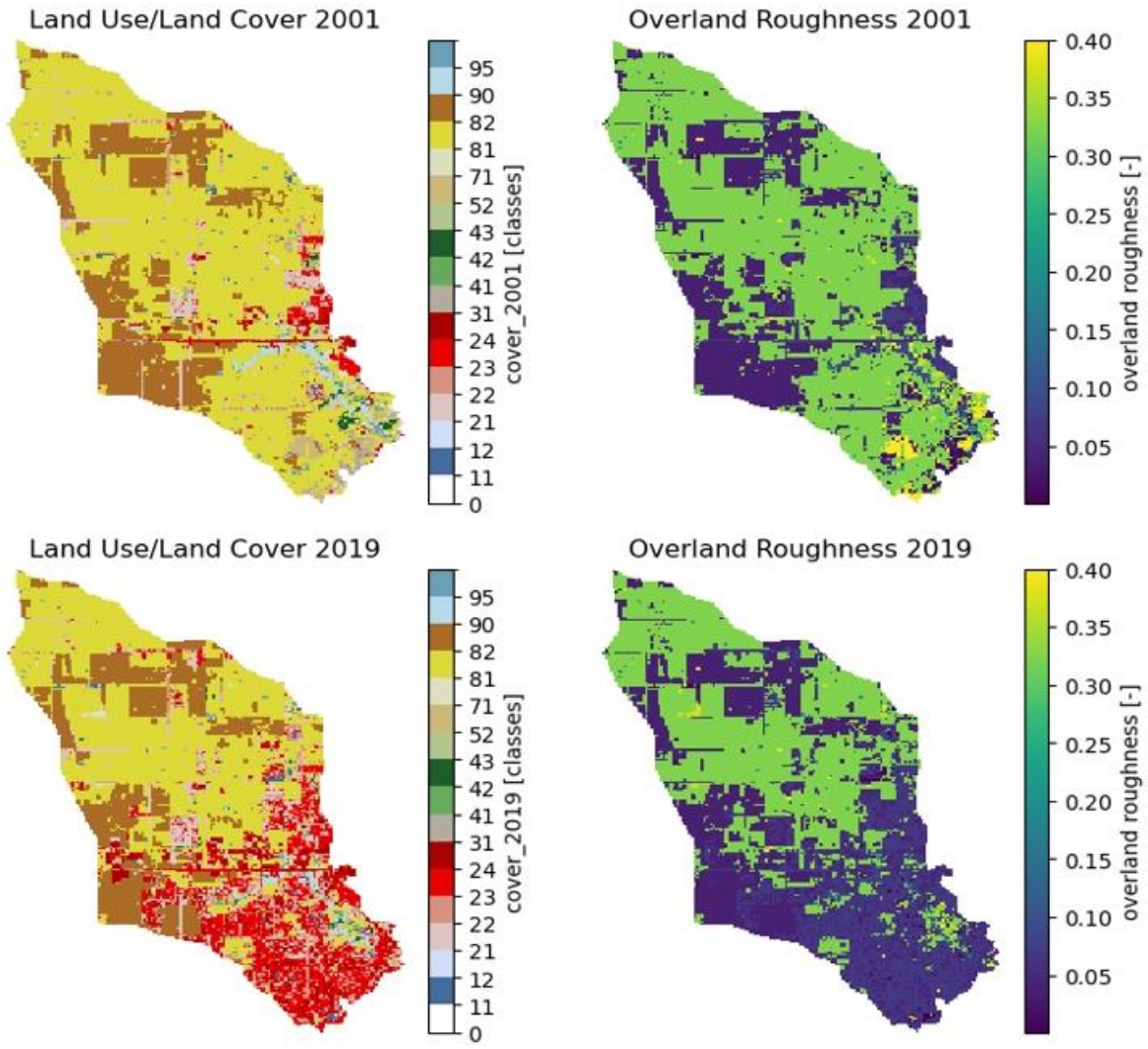

Figure 3.

Land use change from 2001 to 2019 shows a significant increase in the proportion of developed land, particularly in the southern part of the watershed. Correspondingly, land roughness has also increased, and the impervious land (Red colored areas) surface has expanded accordingly.

3. Hydrological Information of the Buffalo Bayou Watershed

Precipitation and observed discharge data show that rainfall is abundant in the Buffalo Bayou near Katy watershed. The top three precipitation events (mm/day) were 343.44, 247.31, and 219.03 on August 27, 2017, April 17, 2016, and May 25, 2015, respectively. The top three runoff events (mm/day) were 238.77, 138.19, and 127.24 on August 28, 2017, August 29, 2017, and August 27, 2017, respectively.

To find the connection between climate and flood, the relationship between precipitation and flood magnitude, timing, and frequency was compared (USGS, 2021).

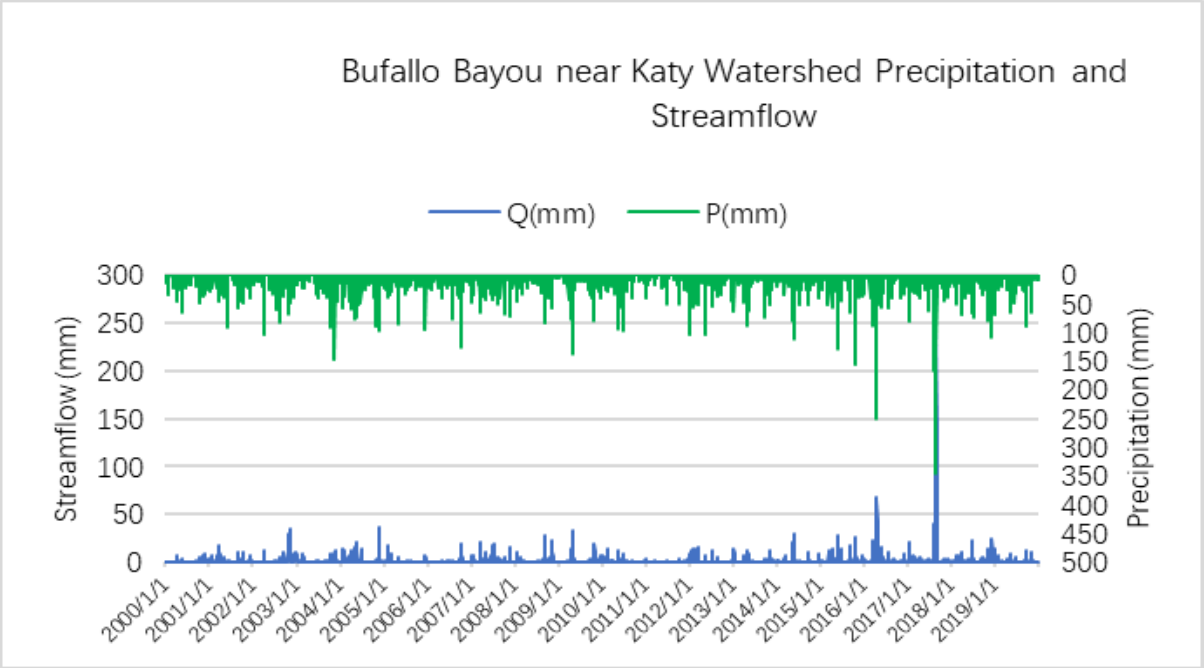

Figure 4. Total Hydrograph and daily precipitation from 2000 to 2019.

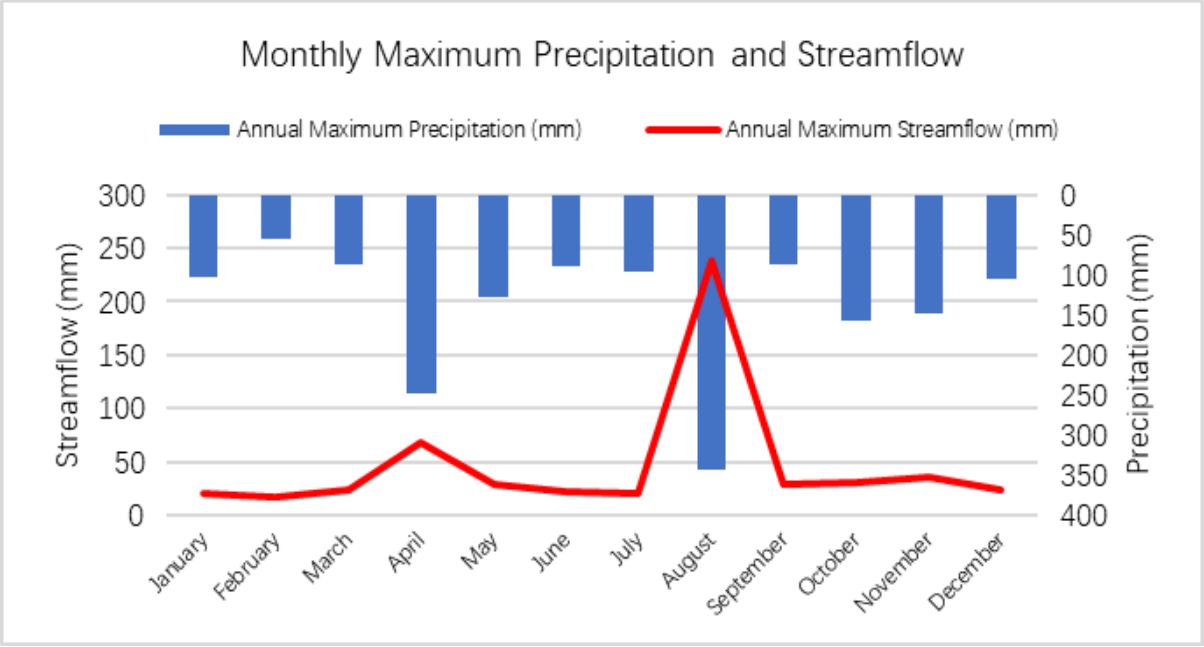

Figure 5. Monthly Maximum Precipitation and Streamflow from 2000 to 2019

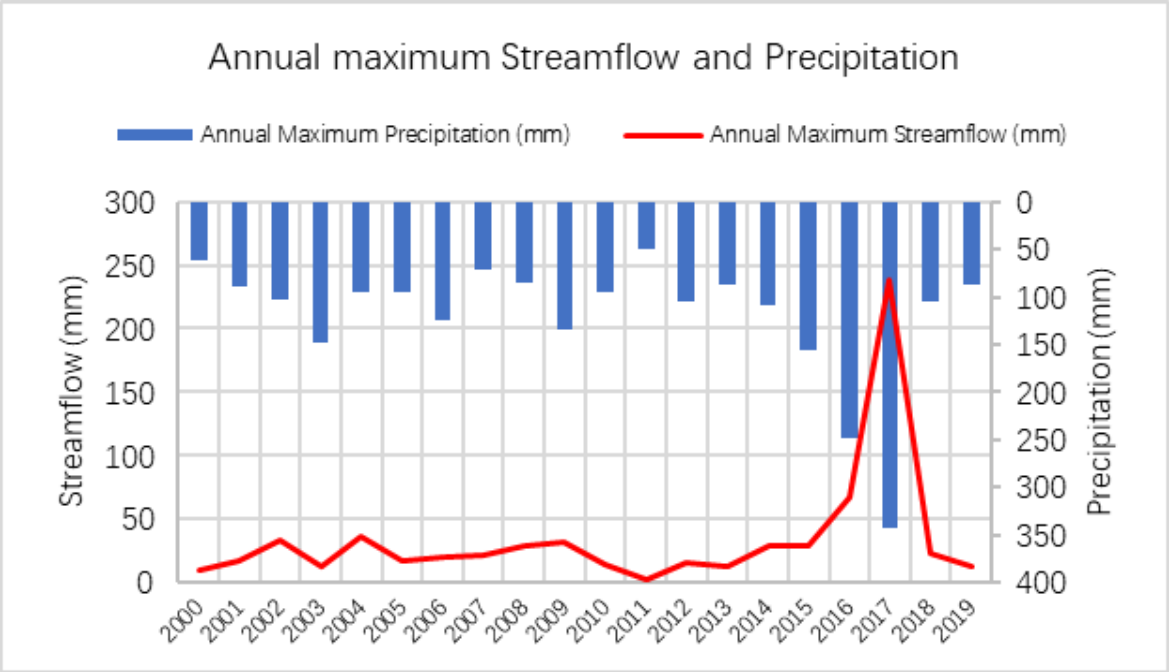

Figure 6. Monthly Maximum Precipitation and Streamflow from 2000 to 2019

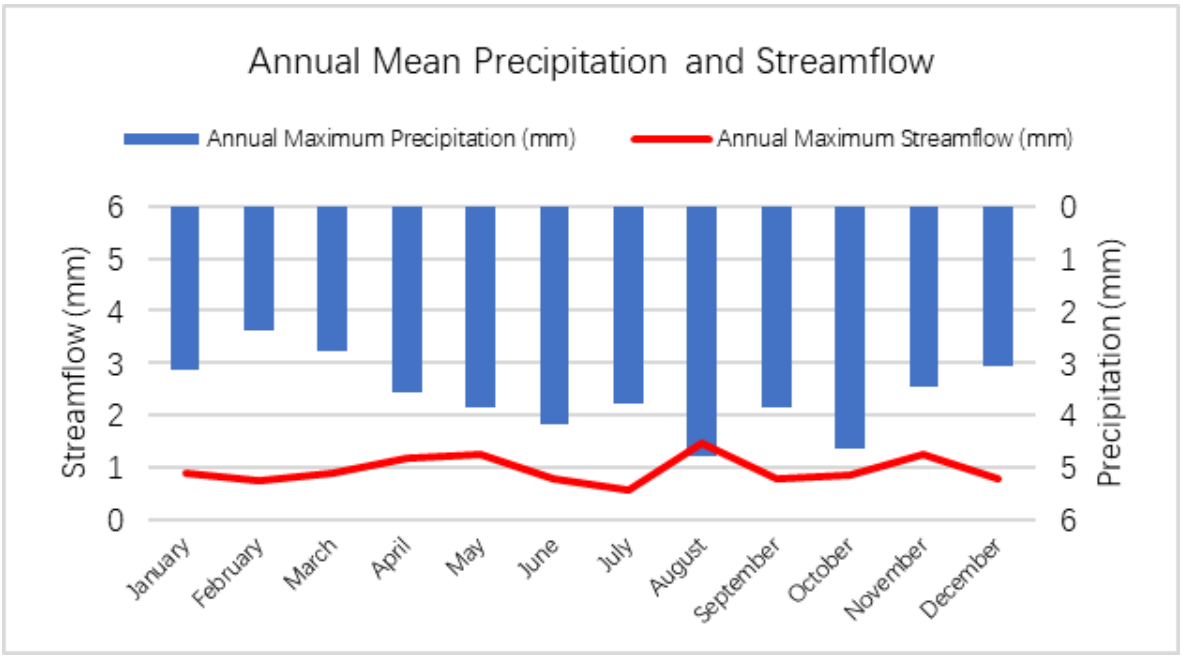

Figure 7. Monthly Mean Precipitation and Streamflow from 2000 to 2019

4. Flood Simulation Model

The hydrological model simplifies hydrological processes and responses, aiding in understanding, predicting, estimating, and managing water resources. This study uses the bucket model to investigate flood mechanism. The bucket model was employed for discharge simulation. This lumped model accounts for the water balance of significant hydrologic cycle processes, such as precipitation, evapotranspiration, infiltration, surface water flow, sub-surface water flow, and groundwater flow. The bucket model effectively describes surface and sub-surface hydrological processes and soil water movement dynamics (Homer et al., 2015).

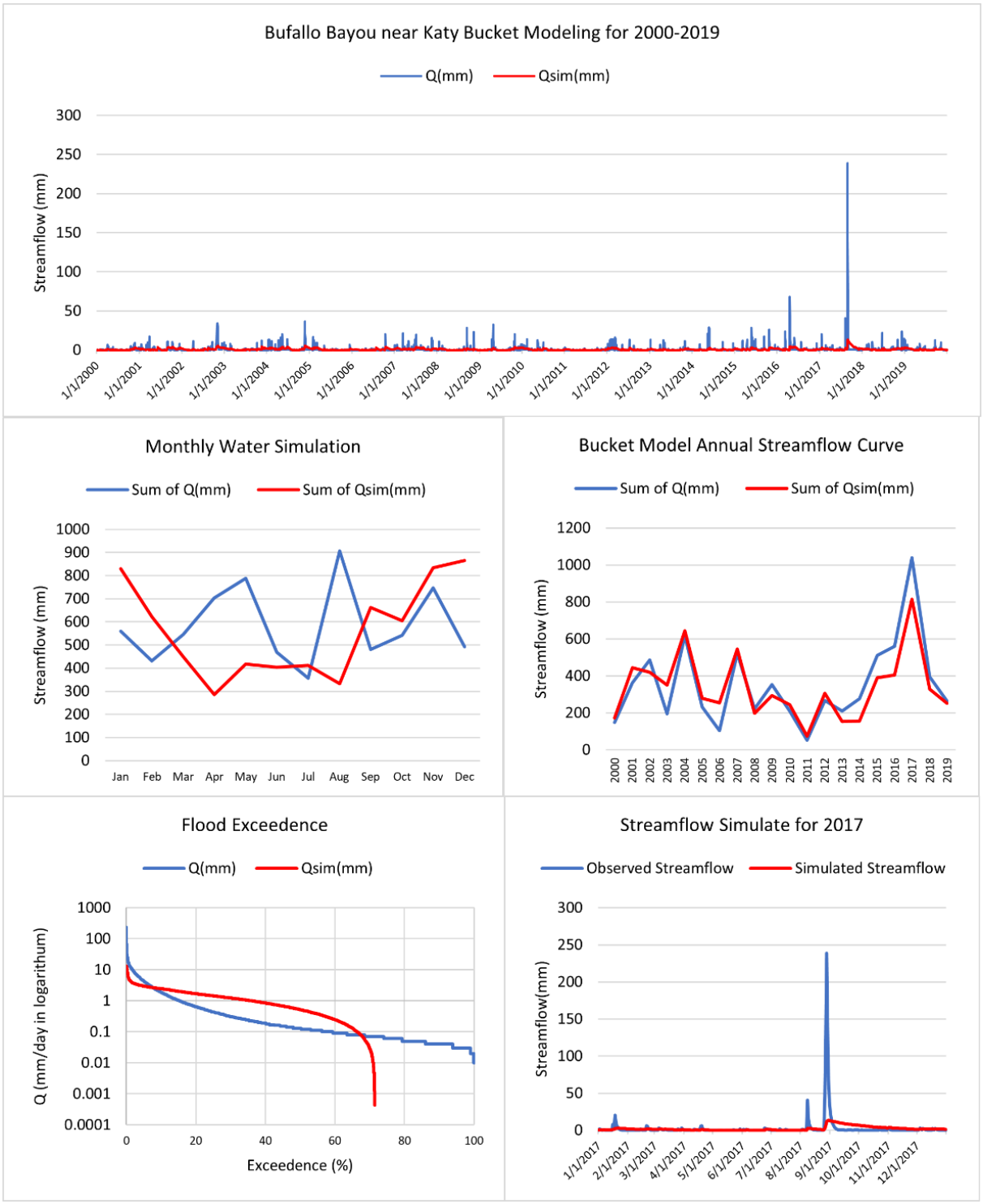

Figure 8. Bucket model simulation

5. Results

The simulations show that all methods have generated reasonable curves and values. To better understand the modeling results, it is necessary to analyze the simulation statistically and physically.

Several statistical indexes check the accuracy of simulation, such as root mean square error (RMSE), Nash-Sutcliffe Efficiency (NSE), and percentage bias. The RMSE value of 3.3 indicates a reasonable level of accuracy. However, the NSE of -0.01 highlights a significant area for improvement. The Percent Bias (PBIAS) of -0.12% suggests a very slight underestimation, showing that the model predictions are well-balanced with minimal systematic error.

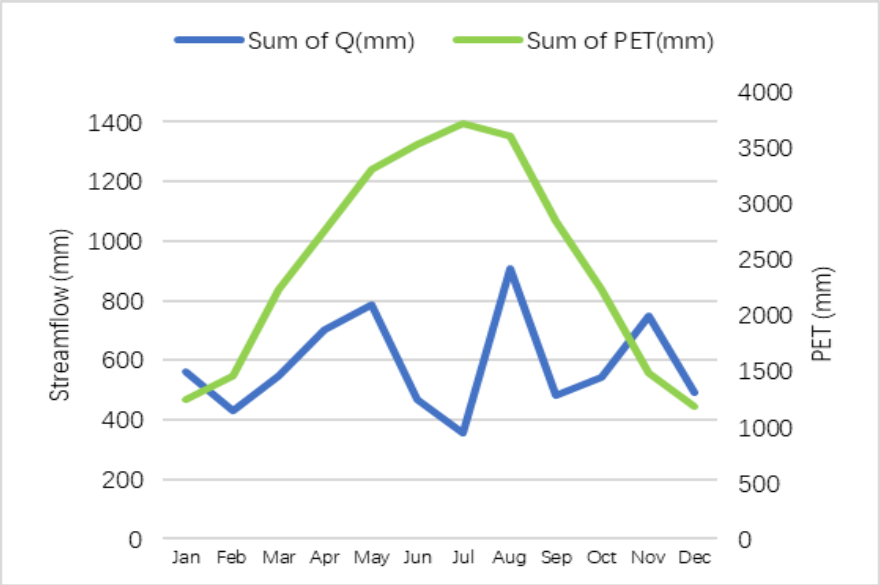

Figure 9. Connection between streamflow and transpiration

Watershed physical and numerical functions can also check model performance; for example, the regime curve and flow duration curve can define water movement dynamic and soil properties. Figure 3-7 and Figure 9 show that land development, precipitation and evapotranspiration are three dominant hydrological processes in the Buffalo Bayou watershed.

6. Discussion and Conclusion

This study investigates the flood mechanisms in the Buffalo Bayou watershed using the bucket model to simulate long-term discharge. The model performs adequately but needs refinement, particularly in better capturing data variability, to enhance its predictive capabilities. The model can be a valuable tool for predicting flood occurrence and magnitude.

In addition to flood prediction, when developing of the watershed, the implementation of flood mitigation measures is essential for managing and reducing flood risks in the Buffalo Bayou watershed. Various flood control structures have been or to be employed within the watershed:

- Addicks and Barker Reservoirs: These reservoirs capture and control floodwaters from the upper portions of the watershed, regulating water flow and mitigating heavy rainfall impacts (U.S. Army Corps of Engineers, 1940s).
- Green Infrastructure: Examples include bioswales, rain gardens, and permeable pavements, which help manage stormwater runoff and reduce flood risks in urban areas (EPA, 2020).
- Infrastructure Improvements: Ongoing projects aim to improve infrastructure resilience, including channel improvements, upgrading drainage systems, reinforcing levees, and retrofitting critical facilities (HCFCD, 2020).
- Community Engagement and Preparedness: Efforts include public education campaigns, flood warning systems, and the development of flood response plans to ensure residents are equipped to handle flood events (HCFCD, 2020).

By investigating the flood history and examining various flood mitigation methods, this study aims to contribute to a better understanding of flood management practices and enhance the resilience of communities within the Buffalo Bayou watershed. Through continuous monitoring, infrastructure improvements, and community engagement, the region can better prepare for and respond to future flood events, safeguarding both lives and property.

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