Impact of Size and Location of Wetlands on Watershed-scale Flood Control

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Abstract

This paper presents a case study on the impact of the size and location of wetlands on watershed-scale flood control utilizing the Cypress Creek Watershed in Houston, Texas as the study area. Wetlands of different sizes were implemented at different locations (upstream, midstream, and downstream) of the watershed and corresponding hydrologic and hydraulic simulations were performed to investigate the impact that wetland size and location parameters have on downstream flood conditions. This study used HEC-HMS as the hydrologic model for the watershed, and HEC-RAS as the hydraulic model for rivers within the watershed. Wetlands were implemented in the HEC-HMS model as reservoirs. Simulation results indicate the more upstream wetlands are located within the watershed, the smaller the flood area, the shallower the flood depth, and the shorter the flood duration at the downstream region of the watershed. In addition, the downstream flood area, flood depth, and flood duration decrease as the size (storage capacity) of wetlands increases.

Keywords: Flood mitigation, HEC-HMS, HEC-RAS, Water storage, Wetland management, Cypress Creek Watershed, Texas

1. Introduction

As cities continue to grow, urban landscapes are constantly changing with more natural areas being replaced with impervious surfaces, like buildings, roads, parking lots, etc. The rapid increase in impervious surface area has led to severe flooding problems in many large cities worldwide, causing considerable damage to people living in the area, including loss of lives, property damage, disruption of transportation, destruction of crops, and deterioration of water quality. In the US, urban stormwater flooding has become a serious

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problem, especially in large densely populated cities subject to frequent rainfall events (Hilten et al. 2008). According to Natural Hazards Research, floods are responsible for more property damage and loss of life in the US than any other type of natural disaster (National Weather Service 2013). Average damage of $6.9 billion/year was estimated by Moser et al. (2014) for inland flooding in the period 1976 - 2006.

To mitigate urban flooding losses, scholars and practitioners have proposed various structural measures, which can be generally categorized into four types: storage, diversion, channel capacity enhancement, and water constriction within the channel (Stephens and Dyhouse 1994, ICE 2001, Breckpot M. 2010). The effectiveness of structural measures for flood control has been debated throughout history. For example, suggestions from scientists, engineers, and the public ranged from building levees along the entire length of the river in question to totally abolishing all the levees (e.g., Parrett and James 1993, Yen 1995, Tobin 1995, The Guardian 2009). Structural measures have been implemented and documented in many real-world cases. Yet, communities world wide are still facing ever-increasing flooding problems.

One underlying common ground of the structural measures is that they are designed on the scale of the flooding area of interest. Their effectiveness is highly limited by their size and location. If one considers the flooding problem on a larger scale, the watershed scale, it can be seen that even though structural measures can alleviate floods in some way, they have very limited capacity because only a very small part of the watershed is used for flood control. Therefore, it is desirable to seek a flood control solution that can provide more storage capacity at the watershed scale.

In response to the ineffectiveness of structural measures, scholars and practitioners are advocating a "watershed approach" in which the entire watershed, as well as the ecological structures, functions, and processes within it, become the goal of management practices (Birkland et al. 2003, Freeman et al. 2003, UNDP and UNISDR 2006). In the watershed approach, the entire watershed is under management so that flooding in one area can be linked to the development upstream or to human practices exerted elsewhere in the natural system. Following this philosophy, the present study investigated how the location and size of wetlands play a role in downstream flooding within a watershed.

There are a few studies regarding wetlands' flood control effect but with slightly different focuses. For example, Smolders et al. (2015) investigated the attenuation effects of estuarine wetlands under a storm tide in the Scheldt estuary (Belgium, Netherlands) and proposed that a larger wetland area generally brings more attenuation up to a threshold. The authors also claimed that for wetlands of the same size and elevation, the more upstream wetlands provide larger attenuation effects on upstream high water levels. Ameli and Creed (2019) investigated how the location of wetlands relative to the main stream network affects the hydrologic resilience of the Nose Creek watershed located within the Prairie Pothole Region of North America. The authors concluded that wetlands closer to the main stream network played a more significant role in attenuating peak flow.

Very few studies have investigated the effect of wetland area and location on flood control for inland wetlands in particular. This study aims to fill this gap by investigating how the implementation and management of a wetland system at different locations (upstream, midstream, or downstream) of a watershed affect flooding in the downstream urban area. The work presented herein is part of a two-component project, of which the overarching goal is to dynamically manage water storage in a system of wetlands for flood mitigation on a watershed scale. The scope of this paper is limited to the effect of the location and size (storage capacity) of wetlands on flood control. This study serves as a foundation for a second paper(Tang et al. 2020), which focuses on the impact of wetland dynamic storage management on watershed-scale flooding.

2. Methodology

The modeling framework of this study consists of two parts: 1) the hydrologic modeling of the watershed, which simulates the rainfall-runoff processes of each subbasin of the watershed; 2) the hydraulic modeling of the rivers within the watershed, which routes outflows from each subbasin through the channels and produces inundation results. Herein, Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) was used for the former and Hydrologic Engineering Center - River Analysis System (HEC-RAS) was used for the latter.

HEC-HMS is a semi-distributed, process-based hydrologic model that can simulate various water quantity related functions for multiple storage enhancement strategies at identified storage sites (existing and/or potential) (Scharffenberg et al. 2010, Zhang et al. 2013). It has the flexibility to explore the effect of multiple water management practices (ponds, wetlands, reservoirs, etc), and can be easily integrated with the HEC-RAS model for flow routing and inundation mapping. From the HEC-HMS model, the flows going into the rivers can be obtained from each sub-basin (with or without wetlands implemented).

The wetlands are simulated as reservoirs in the HEC-HMS model. Outflows from each sub-basin are modeled as the inflows to the wetlands. For subbasins without wetlands, outflows are modeled as lateral flows directly into adjacent rivers. For each wetland (reservoir) in HEC-HMS, the overflow feature is enabled to simulate the overflow using the broad-crested weir flow method. HEC-HMS simulates the water surface level change and the storage change in each wetland, as well as the overflows of each wetland, if there are any.

The flows in rivers are simulated in HEC-RAS, which is coupled with HEC-HMS through Hydrologic Engineering Center - Data Storage System (HEC-DSS). HEC-DSS is a database system designed to store and retrieve scientific data, like time series, spatially gridded data, etc. It is incorporated into most of HEC'S major application programs, including HEC-HMS and HEC-RAS. HEC-RAS can directly retrieve the flow data generated by HEC-HMS for each sub-basin and/or wetland and perform unsteady flow simulations. HEC-RAS then produces flood inundation mapping along the channels.

The flood inundation results produced by the HEC-RAS model are then evaluated to determine the impact of wetlands on various flood parameters such as flood area, flood depth and flood duration. In this study, two major scenarios are investigated: 1) natural condition (no wetlands implemented); 2) wetlands implemented and used as extra storage in the watershed. In the first scenario, the flows from each sub-basin are directly fed into HEC-RAS. In the second scenario, the flows from each sub-basin are routed to the wetlands first, and when the wetlands are completely full, the overflows are then routed to HEC-RAS. Such an assumption was made based on a literature review that showed, most of the inland wetlands in the United States are located in floodplains near rivers or streams (EPA, https://www.epa.gov/wetlands/what-wetland).The inundation results for the two scenarios mentioned above are compared to analyze the effects of wetlands, and by implementing different sizes of wetlands at different locations of the watershed, the impact of the size and location of the wetlands on flood mitigation can then be revealed. A flow chart of the methodology used in this study is shown in Fig. 1.

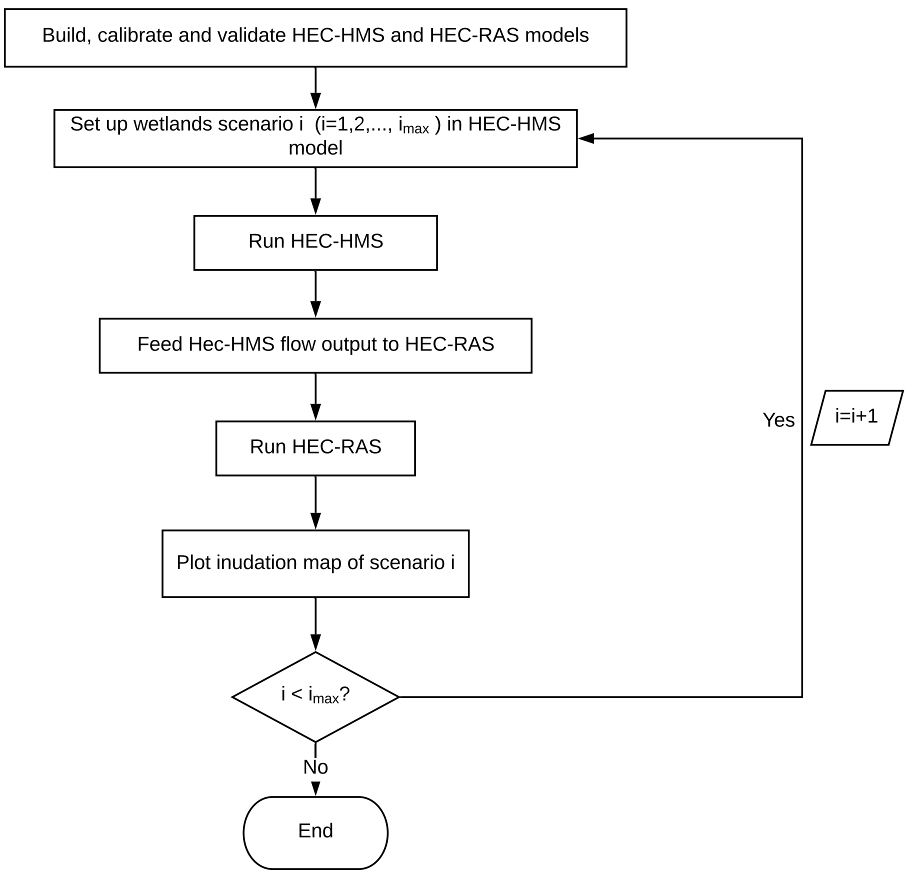

Figure 1. Flow chart of the methodology

3. Case Study

The Cypress Creek Watershed, located in Harris County Flood Control District (Houston, TX), served as the subject of the case study. Fig. 2 shows the geographical location of the watershed. The Cypress Creek Watershed, with a drainage area of 267 square miles, experiences recurrent flooding, about two to three times per year on average (Houston-Galveston Area Council 2016). The watershed also experienced devastating floods during Hurricane Harvey in August 2017 (Lindner and Fitzgerald 2018). The major stream in the watershed, Cypress Creek, originates from the northwest of the watershed, takes a north-south course first, and then changes course to a west-east direction. It is fed by several tributaries along the way, the largest of which is Little Cypress Creek.

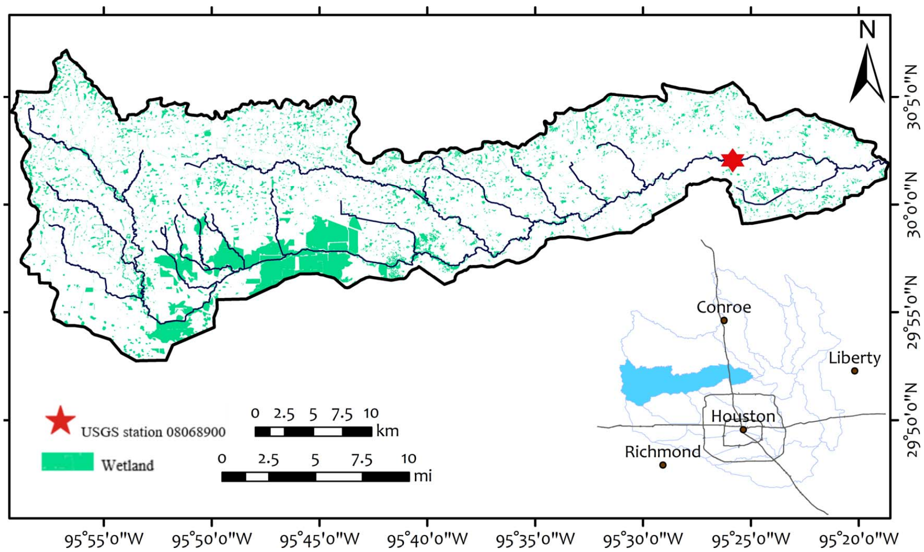

Figure 2. Geographical location of Cypress Creek Watershed, TX

The downstream region of the Cypress Creek Watershed is mainly urban area, while the upstream region is dominated by agriculture. The upstream region was historically covered by wetlands and abandoned rice farms. It is home to a multitude of existing levees that could be easily repaired to restore the function of wetlands. The watershed was previously mapped with high-resolution airborne laser scanning (ALS) observations, and the resultant Digital Terrain Models (DTMs) of the watershed were used to delineate potential wetland catchment areas of at least 929m^2 ($10{,}000\ \text{ft}^2$) with a hydraulic head of at least 0.6m (2ft). The preliminary identification of wetland areas discussed above shows that potential wetland areas constitute about 17% of the total land area for the Cypress Creek watershed.

3.1. Hydrologic Modeling (HEC-HMS)

The hydrologic Model of the Cypress Creek Watershed was developed in HEC-HMS, as shown in the details below.

3.1.1. Model Construction

The Cypress Creek watershed was delineated using a Digital Elevation Model (DEM) with a resolution of 30m. The delineation process partitioned the entire watershed into multiple subbasins, which are the basic hydrologic response unit of the HEC-HMS model.

The SCS curve number (CN) method was used to estimate runoff in each sub-basin in HEC-HMS. A raster dataset of the SCS curve number was prepared for the Cypress Creek Watershed. Curve numbers were determined based on soil and land use class. Soil data of the Cypress Creek watershed were retrieved from the SSURGO soil database (Natural Resources Conservation Service (NRCS) Web Soil Survey) and land use data were retrieved from NLCD 2011 land cover dataset. The soil data was used to extract the hydrologic group of soils (A/B/C/D) at each grid. Group A soils have the highest infiltration rate and the lowest runoff potential, and group D soils have the lowest infiltration rate and the highest runoff potential. The conjunction of the hydrologic group of soils and land use class at a certain grid determines the curve number at that grid. The curve numbers were obtained using the method in SCS TR55 (1986). Fig. 3 displays the curve number grid map generated for the Cypress Creek watershed. With the curve number raster dataset, the curve number for each sub-basin was calculated by area weighting, and serves as the starting point for calibration.

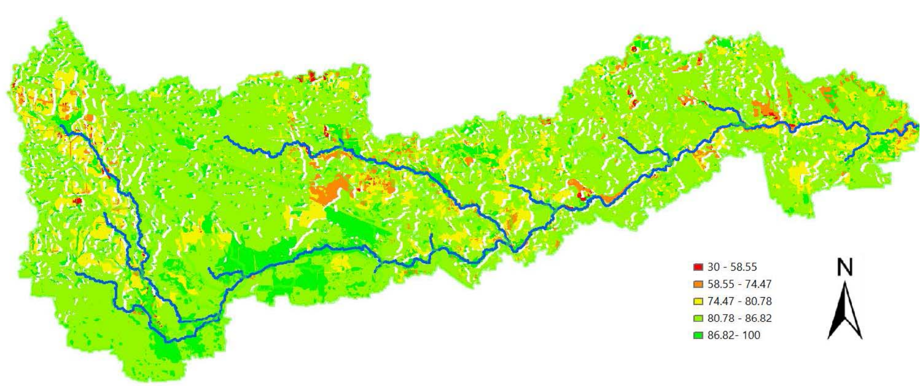

Figure 3. Curve Number Grid Map of Cypress Creek Watershed using SCS TR55 method

The SCS unit hydrograph method was used to generate the runoff hydrograph in HEC-HMS. For each sub-basin, the centroid, the longest flow path, and the basin slope were generated in HEC-GeoHMS based on DEM data. The lag time and time of concentration were estimated for each sub-basin based on sheet flow and shallow concentrated flow equations. For detailed calculation process, the reader is referred to SCS TR55 (1986). The length of sheet flow was assumed to be 100ft based on suggestions in SCS TR55 (1986), and the shallow concentrated flow length was calculated using the longest flow path of each sub-basin subtracted by the length of sheet flow. The calculated lag time for each sub-basin is the starting point for calibration.

3.1.2. Model Calibration and Validation

The HEC-HMS model was calibrated and validated by comparing the simulated and observed flow at USGS station 08068900 (labeled as a red star in Fig. 2) from 2001 to 2009. This is the USGS station closest to the outlet of the watershed that has flow data available. The reason this location was chosen as the calibration site is because the calibrated parameters would be applicable to most of the contributing area to the outlet. Rainfall and flow data used in model calibration and validation are in daily resolution, as hourly data is not available for long periods of time at this station. Calibrated parameters include the following: curve number scale parameter, base flow scale parameter, evaporation scale parameter, SCS unit hydrograph lag time scale parameter, canopy storage capacity in sub-basins, and initial abstraction ratio.

In the field of hydrology, Nash-Sutcliffe Coefficient is frequently used as an indicator of the goodness of fit for a hydrologic model. Researchers (Moriasi et al. 2007) suggest that a Nash-Sutcliffe Coefficient above 0.5 indicates a good fit between the simulated data and the observed data. A model with a Nash-Sutcliffe coefficient of 0.5 or above can be used for modeling and prediction purposes of the hydrologic behavior of a watershed. Nash-Sutcliffe coefficient is defined as follows:

$$NS = 1 - \frac{\sum_{t=1}^{T}(Q_m^t - Q_o^t)^2}{\sum_{t=1}^{T}(Q_o^t - \bar{Q_o})^2} \tag{1}$$

where Q_m^t is modeled discharge at time t, Q_o^t is observed discharge at time t, and $\bar{Q_o}$ is the mean value of observed discharges.

The calibration was performed at the above-mentioned station with the rainfall and flow data in 2001. Using Equation 1, the calculated Nash-Sutcliffe Coefficient was 0.7 for the calibration period. Following calibration, the model was validated from 2002 to 2009 at the same station using historical rainfall data and observed flow data, as shown in Fig. 4. It can be seen that generally, the model produced good match of flood peaks during heavy rainfall events. The Nash-Sutcliffe Coefficient calculated was approximately 0.6 for the validation period. As such, the model can be considered sufficient for modeling and prediction purposes since the physical features of the watershed are now well-represented by the model after calibration and validation.

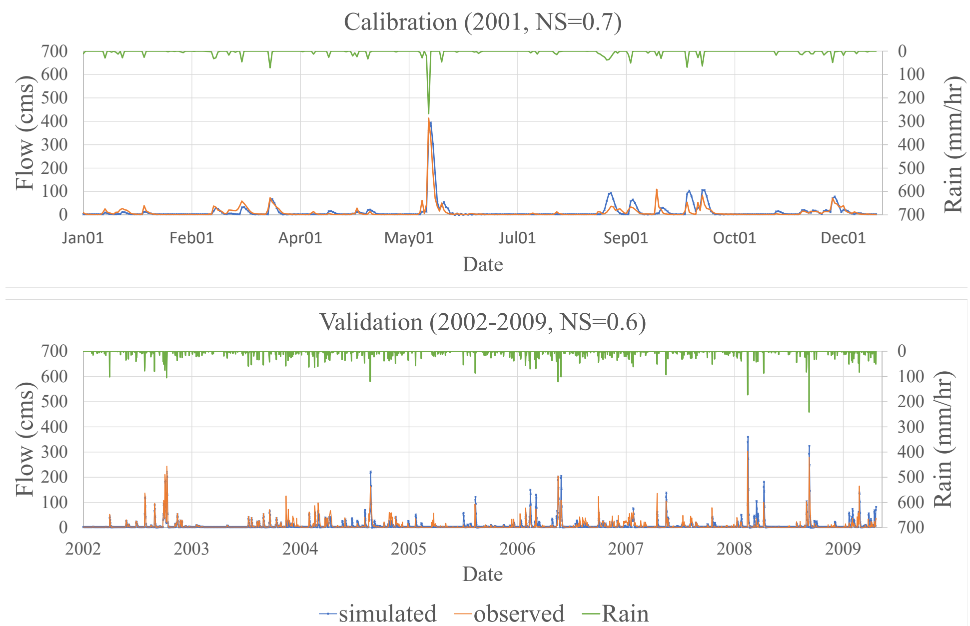

Figure 4. Calibration of the HEC-HMS model

3.2. Hydraulic Modeling (HEC-RAS)

A 1D HEC-RAS model of the major rivers in the Cypress Creek Watershed was developed in HEC-RAS. A DEM with a finer resolution, 3m, was used to obtain the bathymetry of the river. The HEC-RAS model was used to perform unsteady flow simulation, using the simulated sub-basin outflows from the HEC-HMS model. If a sub-basin contains wetlands, then the sub-basin outflows enter the wetlands first, and the wetlands' outflows will then enter the HEC-RAS model as lateral inflows. The link of flow data between HEC- HMS and HEC-RAS was through HEC-DSS.

The Manning's roughness of the rivers was set to 0.03 for the main channel, and 0.06 for the overbank based on local conditions of Cypress Creek (fairly straight, clean, no rifts or deep ponds, with some slight brush and trees on overbank in summer) based on the reference table of Manning's roughness for Channels (Chow 1959).

3.3. Design Rainfall Event

Because the present framework is intended for design purposes, a 100-year 72-hour design rainfall event was developed for all subsequent simulations. According to the Atlas of Depth-Duration Frequency (DDF) of Precipitation Annual Maxima for Texas (USGS 2004), the cumulative rainfall for a 100yr 72hr event is 14.3in for the region. The design rainfall distribution was established based on a Texas empirical hyetograph study (Williams-Sether et al. 2004). The authors analyzed rainfall data from 1,659 runoff-producing storms near 91 U.S Geological Survey streamflow-gauging stations in north and south central Texas and presented statistics for the empirical, dimensionless, cumulative-rainfall hyetographs in their report along with hyetograph curves and tables, which can be used to estimate the distribution of rainfall in urban and small rural watersheds in Texas. The median hyetograph from table "supplement 5" in Sether's report (https://pubs.usgs.gov/sir/2004/5075/pdf/sir2004-5075.pdf, pg 124) was used to develop the design rainfall hyetograph for this study, as shown in Fig. 5.

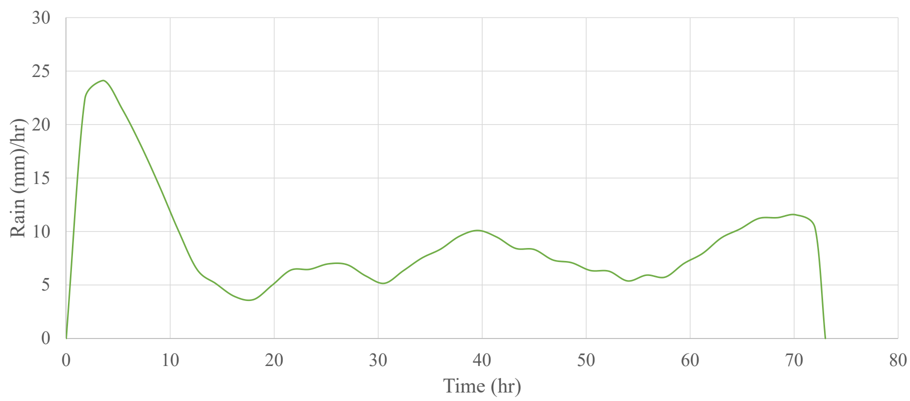

Figure 5. Temporal distribution of the 100-yr 72-hour design rainfall event

4. Results

Simulations were performed for the Cypress Creek watershed by implementing different sizes of wetlands at different locations of the watershed. To simulate the entire process of a flooding event, the simulation period was set to 7 days, with rainfall occurring from day 3 to day 5. The simulated results for different scenarios were compared in this section to evaluate the performance of the wetlands regarding their storage capacity and location.

4.1. Impact of Wetland Location

To facilitate the analysis of the location impact of wetlands, the whole watershed was divided into three regions: upstream, midstream, and downstream, as shown in Fig. 6. The total area of the sub-basins located in the upstream, midstream, and downstream regions of the watershed are $2.55 \times 10^8 \mathrm{m}^2, 2.88 \times 10^8 \mathrm{m}^2, 2.9 \times 10^8 \mathrm{m}^2$, respectively, which are relatively of the same magnitude.

In this study, the authors are primarily interested in the flood conditions in the downstream urban area as flooding usually causes the most damage here. To analyze the effects of wetland location on downstream flooding, wetlands were implemented in the upstream, midstream, and downstream regions, respectively, with the same total storage capacity. The flooded area at the downstream region was computed and compared for the three scenarios, which indicates the effects of the wetland location on downstream flooding.

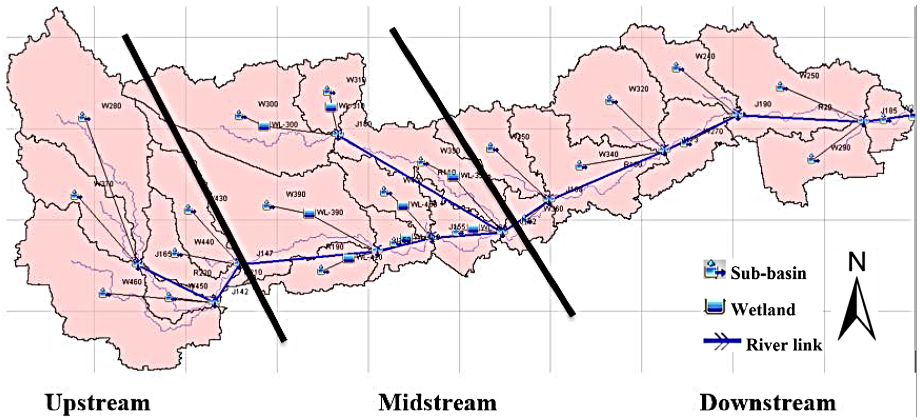

Figure 6. Division of the Watershed into Up, Middle, and Downstream Region

Wetland implementation were not in a lumped format, but rather distributed in each sub-basin within the above-mentioned three regions in each scenario, because sub-basin is the basic hydrologic response unit within HEC-HMS. As such, wetland size was represented by the percentage area of each sub-basin in which the wetlands were implemented. Initial scanning of the DTM data showed that most of the natural depressions that can be engineered to function as wetlands have a depth of around 0.9m (3ft), thus the maximum wetland water depth was assumed to be 0.9m (3ft) in the HEC-HMS model. In each of the three scenarios, a total area of $2.88 \times 10^7 \mathrm{m}^2$, representing around 3.5% of the total watershed area, was assumed to be used for wetlands. The wetlands were proportionally distributed within each sub-basin, based on the sub-basin area. The downstream flood condition from the three scenarios was compared to assess the location impact that wetlands have on downstream flooding.

The initial water depth of the wetlands was set to 0.15m (0.5ft) to reflect the minimum water depth required to sustain the ecological function of the wetlands, like supporting local hydro-habitat and biodiversity.

Flood area was defined as the difference between the maximum inundation area and the area of water bodies (e.g. rivers, ponds). Table 1 summarizes the maximum downstream flood area for the three wetland location scenarios, as well as the maximum flood depth and flood duration in the downstream urban areas. The flood depth and flood duration vary significantly at different locations in the downstream watershed. The maximum flood depth and flood duration usually occur in areas of depression that may not be inhabited. To better quantify the influence that flooding exerts upon human development, the flood depth map of the inhabited areas was analyzed. It was found that maximum flood depth and flood duration occur near the Kenchester Park neighborhood in all three scenarios. Fig. 7 shows the extent of flooding in this neighborhood for all three scenarios (with flood depth color-coded). Fig. 8 shows how the flood depth varies with time at the most severely flooded location within the Kenchester Park neighborhood for all three location scenarios.

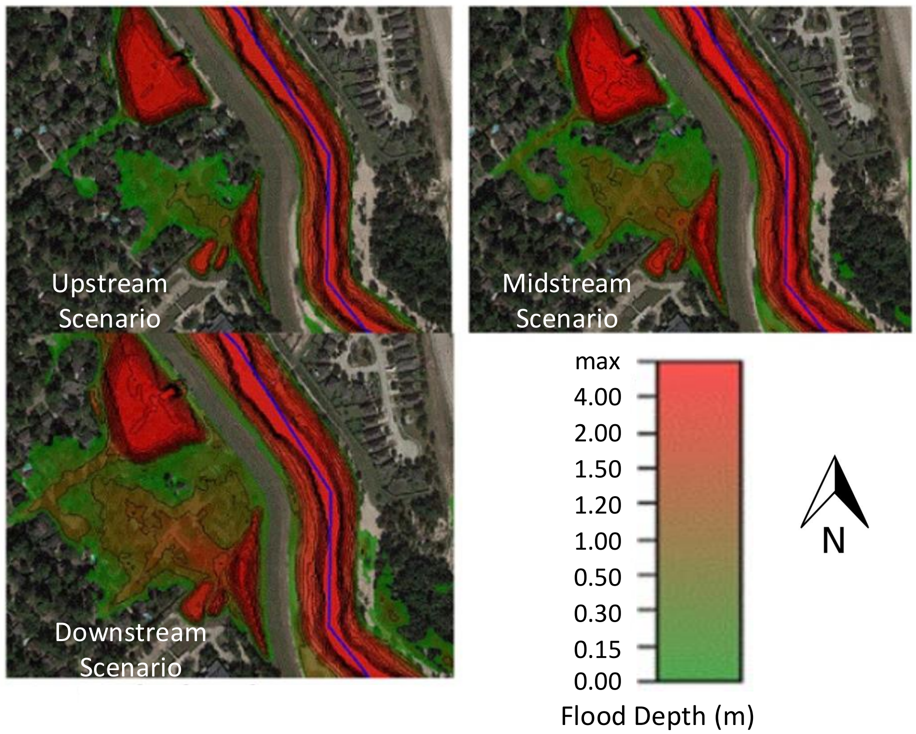

Figure 7. Maximum flood extent and flood depth (m) in Kenchester Park neighborhood for three location scenarios

280 Table 1 and Figs. 7 - 8 suggest that the further upstream the wetlands are implemented, the smaller the flood area, the maximum flood depth, and the maximum flood duration are in the downstream region. This difference is most likely due to the different travel times of the flows arriving at the downstream region. For example, when wetlands are implemented in the upstream region, hillslope flows in the upstream region are initially held in wetlands. When wetlands become full after a time delay Δt, then the overflows will enter the river. During this time delay Δt, a portion of the high flows from the midstream and downstream regions are already conveyed out of the watershed, which makes room in the downstream channel to convey the upstream flows after wetlands become full. On the other hand, if wetlands are implemented in the downstream region, the initial flows in the downstream channel may be small due to the retention of wetlands and also because the high flows from upstream and midstream regions may not arrive at the downstream channel yet. However,

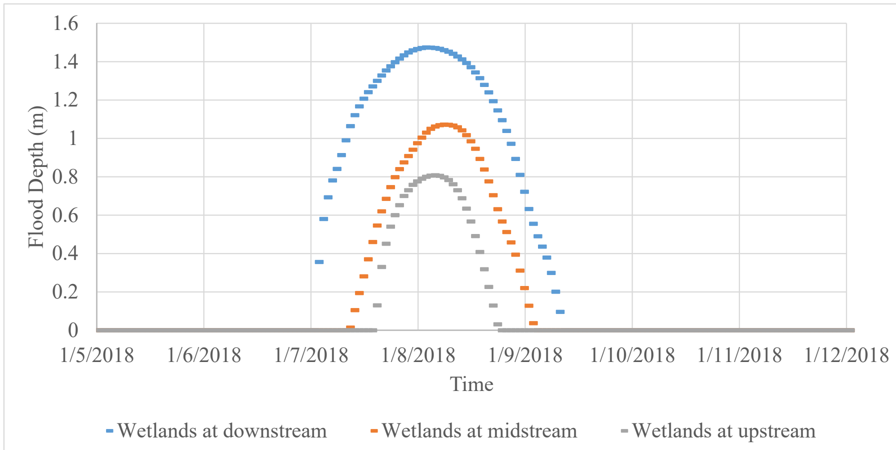

Figure 8. Flood depth variation with time at the most severely flooded location within Kenchester Park neighborhood

after time delay Δt wetlands become full, and overflows from the downstream
295 region and high flows from the upstream and midstream regions may arrive at the downstream channel at the same time, which is a peak-to-peak situation in the worst case. Hence, flooding can be exacerbated in terms of flood area, flood depth and flood duration.

Table 1. Downstream maximum inundation area, inundation depth and inundation duration when same size of wetlands (3.5% of the total watershed area) are implemented in upstream, midstream, and downstream regions, respectively

Wetland Location	Max Downstream flood area (m^2)	Max flood depth in downstream urban area (m)	Max flood duration in downstream urban area (hr)
Wetland in upstream	$6.43E+06$	0.81	28
Wetland in midstream	$8.10E+06$	1.08	42
Wetland in downstream	$1.13E+07$	1.47	55

4.2. Impact of Wetland Size

300 To analyze the effects of wetland size, wetlands of different sizes are initially implemented and analyzed in all three aforementioned regions. Overall, the results indicate that downstream flood conditions improve when wetland size increases, no matter which region they are located. More specifically, a slightly better flood control effect is obtained when wetlands are located in the upstream

region. The second best flood control is obtained when wetlands are located in the midstream region. Due to paper length limitations, herein, only the detailed results for the midstream scenario are presented. We focused on the midstream region because in the Cypress Creek Watershed, most of the natural wetlands, abandoned rice fields, and areas of depression that could be engineered as wetlands for flood control are located in the midstream region.

As mentioned earlier, wetland size was represented by the percentage area of each sub-basin in which the wetlands were implemented. In this section, 10 scenarios of wetland sizes were simulated, with 2% to 20% of the area of each sub-basin within the midstream region used as wetlands (representing 0.7% to 6.9% of the total watershed area). All other assumptions of the wetlands are kept the same as in the analysis above, including the initial water depth of 0.15m (0.5ft) and the maximum water depth of 0.9m (3ft) in the wetlands. Table 2 summarizes the maximum downstream flood area for the 10 scenarios of wetland size. This table also presents the maximum flood depth and flood duration in the downstream urban area for all 10 scenarios. Fig. 9 shows the flood depth variation with time at the most severely flooded location within the Kenchester Park neighborhood for all the scenarios.

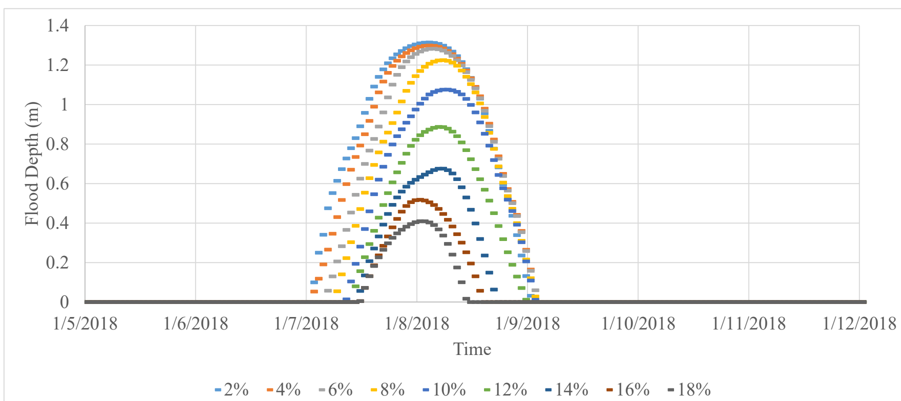

Figure 9. Flood depth variation with time at the most severely flooded location within Kenchester Park neighborhood when different sizes of wetlands were implemented

A sensitivity analysis was performed for the flood area at the downstream region, the maximum flood depth and flood duration in inhabited areas (Kenchester Park neighborhood), compared to the size of the wetlands located in the midstream region of the watershed, as shown in Fig. 10.

Results indicate that flood area, maximum flood depth, and maximum flood duration decrease as wetland size increases. It can be seen that 16% of wetlands in each midstream sub-basin (representing 5.5% of total watershed area) can reduce the flood area by approximately 93%. In the scenario of 18% wetlands (6.2% of total watershed area), the flood area at the downstream region becomes negligible. Flood area does not decrease proportionally to the increase of the

Table 2. Downstream region's flood area, max flood depth, and max flood duration in inhabited area with different sizes of wetlands implemented in the midstream region

Wetland percentage area of each sub-basin within midstream region	Max Downstream flood area (m^2)	Max flood depth in downstream urban area (m)	Max flood duration in downstream area (hr)
0%	$6.18E + 06$	1.46	55
2%	$4.59E + 06$	1.31	48
4%	$4.47E + 06$	1.30	48
6%	$4.34E + 06$	1.28	46
8%	$3.98E + 06$	1.22	44
10%	$3.13E + 06$	1.08	42
12%	$2.21E + 06$	0.89	38
14%	$1.12E + 06$	0.68	30
16%	$4.72E + 05$	0.52	27
18%	$1.78E + 04$	0.41	24

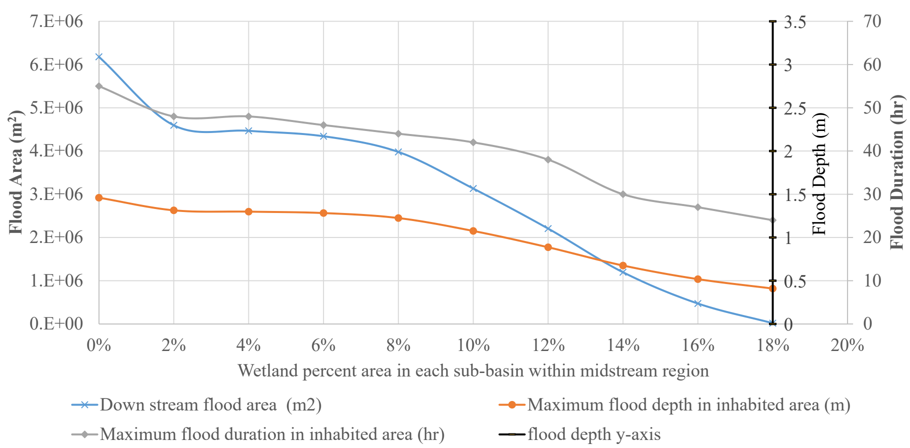

Figure 10. Sensitivity analysis of downstream region's inundation area, maximum inundation depth and inundation duration versus wetland size

wetland size. 2% wetlands (0.7% of total watershed area) can almost reduce the downstream region's flood area by 25%, but it should be noted that the decreased flood area in this stage is mostly just the shallow areas. From 2% to 6% (0.7% to 2.1% of total watershed area), the flood area does not decrease much, but the maximum flood depth and flood duration continue to decrease even though the flood area does not change much.

5. Discussion

The results of this study reveal that inland wetlands can alleviate floods when used as extra storage in the watershed. The more upstream wetlands are located, the better flood control effect they provide. In general, flood area, flood depth and flood duration decrease as the size of the wetland increases. Moreover, when wetland size increases to a certain level, downstream flooding can be eliminated.

The results were summarized based on the case study of the Cypress Creek Watershed, which is a fairly small watershed with relatively sequential river geometry. Further analysis should include a case study with a larger and more complex watershed to address other geometries in which the source area is more spread out and the river system is not lineal, but with more branches draining in parallel rather than in series. In such a complex watershed, there will be more independent large sub-basins that deliver flows to the downstream region.

Regarding the hydraulics of the rivers, the present study only estimated channel roughness using Chow (1959)'s Manning's n table for open channels based on local conditions of the Cypress Creek. In future studies, it is desirable to calibrate the channel roughness using long-term water-surface level data. This will enhance the accuracy of the downstream flooding patterns. There have been few studies investigating the hydraulic regimes of rivers in different flow conditions, ranging from extreme events to low flow events, such as the studies of Kuriqi and Ardiclioglu (2018) and Ardiclioglu and Kuriqi (2019). Although the present study mainly focuses on wetlands' hydrologic functions rather than river hydraulics, the authors believe that calibration of the river hydraulics could improve the accuracy of the results.

6. Conclusions

The work presented herein is part of a long term project, of which the overarching goal is to dynamically manage the storage of wetlands to mitigate floods at the watershed scale. The scope of this paper is limited to the impact that location and size of wetlands have on flood control. The key findings are as follows:

1. Wetland implementation at different locations of a watershed can substantially modify the downstream flooding patterns. For the same size of wetlands, the more upstream they are located, the smaller the flood area, the flood depth and the flood duration are in the downstream region. For

example, when 10% of wetlands are implemented in the three aforementioned regions (around 3.5% of the total watershed area), the upstream scenario (wetlands implemented in upstream) displays approximately 50% less flood area than the downstream scenario (wetlands implemented in downstream region).

2. The downstream flood area, flood depth, and flood duration decrease as the size of the wetlands increases. In the Cypress Creek Watershed, when around 18% of the midstream sub-basins (around 6.2% of the total watershed area) are used as wetlands, downstream flooding can essentially be eliminated.

In summary, wetlands can play a significant role on watershed-scale flood control. Both the size and location of wetlands have a significant impact on downstream flooding patterns. The flooding patterns may be influenced by particular topographic and geometric conditions. It is recommended to perform a detailed hydrologic and hydraulic study for each specific application.

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