1. Title. **Analyzing the Impact of Land Use Changes on Urban Flood Risk in Northwest Houston, Texas, and Prediction of Future Flood Vulnerability**

2. Project Type. Research

3. Focus Categories. Floods (FL), Hydrology (HYDROL), Management and Planning (M&P).

4. Research Category. Climate and Hydrologic Processes

5. Keywords. Urban Flooding, Land Use Change, Development Planning, Stormwater Management

6. Start Date. 3/1/2017

7. End Date. 2/28/2018

8. Principal investigator(s).

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*Advisor:* Dr. Philip Bedient, Herman Brown Professor of Engineering, Civil and Environmental Engineering. Rice University, 6100 Main Street, Houston, TX 77005. Email: bedient@rice.edu Phone: 713-328-4953

9. Congressional District 2nd District

10. Abstract.

In recent decades, Houston, Texas has become one of the fastest growing urban areas in the country and is projected to continue expanding in the next several decades. While development is beneficial in many ways, there is substantial concern that changes in land use have exacerbated urban flooding from large rainfall events, and that future development could worsen impacts to vulnerable areas. Many highly developed watersheds in Houston have already become susceptible to catastrophic flooding (Bass et al, 2016), and other rapidly developing watersheds could face similar situations in the coming decades.

The recent Tax Day extreme rainfall event (April 2016) resulted in catastrophic flooding in northwest Houston, and throughout the county flooded almost 10,000 homes and almost 3,000 apartments (Lindner, 2016). Furthermore, the storm resulted in 8 flood-related fatalities. The magnitude of damages and loss of life caused by this event has motivated serious re-assessment of current flood infrastructure and flood policy in Harris County.

**This study seeks to understand the relationship between development activity and flood risk by assessing long-term changes in flood risk under evolving land use conditions for the Cypress Creek watershed**, which is located in northwest Houston, Texas. Distributed hydrologic and 1D hydraulic models are used to quantify changes in the floodplain for historical land use conditions, and to analyze the spatial relationship between increased development and increased flood risk. Specifically, this study will attempt to quantify increases in the floodplain attributable to land use changes and analyze the relationship between areas where development occurs and areas that experience increased flood risk. Finally, this study aims to predict future potential flood risk by modeling projected land use conditions in 2040. **The results of this study can inform decision-makers and urban planners about vulnerable areas in the watershed, could motivate efforts to proactively mitigate future increases in the floodplain, and could even guide changes in development policies.**

## 11. BUDGET BREAKDOWN

| Cost Category | Federal | Non-Federal | Total |
|---|---|---|---|
| 1. Salaries and Wages | $2,166 | $3,952 | $6,118 |
| - Principal Investigator(s) | | $3,952 | |
| - Graduate Student(s) | $2,166 | | |
| - Undergraduate Student(s) | | | |
| - Others | | | |
| 2. Fringe Benefits | $0 | $933 | $933 |
| - Principal Investigator(s) | | $933 | |
| - Graduate Student(s) | | | |
| - Undergraduate Student(s) | | | |
| - Others | | | |
| 3. Tuition | | | |
| - Graduate Student(s) | $834 | $0 | $834 |
| - Undergraduate Student(s) | $834 | | |
| Total Tuition | | | |
| 4. Supplies | $1000 | $0 | $1000 |
| 5. Equipment | | | |
| 6. Services or Consultants | | | |
| 7. Travel | $1000 | $0 | $1000 |
| 8. Other direct costs | | | |
| 9. Total direct costs | | | |
| 10a. Indirect costs on federal share | XXXXXXX | $2,760 | $2,760 |
| 10b. Indirect costs on non-federal share | XXXXXXX | $2,354 | $2,354 |
| 11. Total estimated costs | $5,000 | $10,000 | $15,000 |
| Total Costs at Campus of the University on which the Institute or Center is located. | $5,000 | $10,000 | $15,000 |
| Total Costs at other University Campus Name of University: | $0 | $0 | $0 |

## 12. BUDGET JUSTIFICATION

**Salaries and Wages for PIs.** Provide personnel, title/position, estimated hours and the rate of compensation proposed for each individual.

Professor Phil Bedient will contribute effort equal to 0.25% of academic year time salary

**Salaries and Wages for Graduate Students.** Provide personnel, title/position, estimated hours and the rate of compensation proposed for each individual. (Other forms of compensation paid as or in lieu of wages to students performing necessary work are allowable provided that the other payments are reasonable compensation for the work performed and are conditioned explicitly upon the performance of necessary work. Also, note that tuition has its own category below and that health insurance, if provided, is to be included under fringe benefits.)

Avantika Gori (PI of record) will work 135 hours on the grant at a rate of $16/hour

**Salaries and Wages for Undergraduate Students.** Provide personnel, title/position, estimated hours and the rate of compensation proposed for each individual. (Other forms of compensation paid as or in lieu of wages to students performing necessary work are allowable provided that the other payments are reasonable compensation for the work performed and are conditioned explicitly upon the performance of necessary work. Also, note that tuition has its own category below and that health insurance, if provided, is to be included under fringe benefits.)

**Salaries and Wages for Others.** Provide personnel, title/position, estimated hours and the rate of compensation proposed for each individual.

**Fringe Benefits for PIs.** Provide the overall fringe benefit rate applicable to each category of employee proposed in the project. . Note: include health insurance here, if applicable.

The fringe benefit rate for Professor Bedient is 0.25% of academic year time faculty fringe benefits (23.6%)

**Fringe Benefits for Graduate Students.** Provide the overall fringe benefit rate applicable to each category of employee proposed in the project. Note: include health insurance here, if applicable.

**Fringe Benefits for Undergraduate Students.** Provide the overall fringe benefit rate applicable to each category of employee proposed in the project. Note: include health insurance here, if applicable

**Fringe Benefits for Others.** Provide the overall fringe benefit rate applicable to each category of employee proposed in the project. . Note: include health insurance here, if applicable.

**Tuition for Graduate Students.**

$834 Tuition Remission at a rate of 38.5%.

**Tuition for Undergraduate Students**

**Supplies.** Indicate separately the amounts proposed for office, laboratory, computing, and field supplies. Provide a breakdown of the supplies in each category.

$1000 will be spent to purchase high resolution radar rainfall data from Vieux and Associates

**Equipment.** Identify non-expendable personal property having a useful life of more than one (1) year and an acquisition cost of more than $5,000 per unit. If fabrication of equipment is proposed, list parts and materials required for each, and show costs separately from the other items. A detailed breakdown is required.

**Services or Consultants.** Identify the specific tasks for which these services, consultants, or subcontracts would be used. Provide a detailed breakdown of the services or consultants to include personnel, time, salary, supplies, travel, etc.

**Travel.** Provide purpose and estimated costs for all travel. A breakdown should be provided to include location, number of personnel, number of days, per diem rate, lodging rate, mileage and mileage rate, airfare (whatever is applicable).

$1,000 will be spent to present the results of the study at the 2017 AGU Conference

**Other Direct Costs.** Itemize costs not included elsewhere, including publication costs. Costs for services and consultants should be included and justified under "Services or Consultants (above). Please provide a breakdown for costs listed under this category.

**Indirect Costs.** Provide negotiated indirect ("Facilities and Administration") cost rate.

The indirect costs will be 0.25% of academic year time faculty IDC. F&A rate at the approved rate of 56.5%.

13. Title. **Analyzing the Impact of Land Use Changes on Urban Flood Risk in Northwest Houston, Texas, and Prediction of Future Flood Vulnerability**

14. Statement of regional or State water problem**:**

Effective stormwater management has become one of the leading infrastructure challenges in large urban/metropolitan areas across the state of Texas. Specifically, the Houston metropolitan region has been devastated in recent years by extreme floods that have caused widespread damage to residences, commercial properties, and critical infrastructure. One such event, the Memorial Day storm (May 25th 2015), dropped over 12 inches of rain in parts of southwest Houston and resulted in almost 3,000 flooded homes as well as seven drowning fatalities (Lindner, 2015). In 2016, the Tax Day storm (April 17th) similarly devastated the west side of Houston with up to 19 inches of rain, and caused over 10,000 homes to be inundated (Lindner, 2016). These recent extreme events have motivated serious actions by the City of Houston to investigate potential changes in flood policy or mitigation options. **Thus, this research study would well-situated to inform Houston policy-makers about one of the most vulnerable regions of the city.**

It has been widely demonstrated that flood impacts from these large rain events are amplified in areas of high development or impervious cover, and that increases in impervious cover result in higher peak flows and total runoff volumes (Bhaduri et al, 2000; Surya & Mudgal, 2011; Singh & Singh, 2011). Specifically in Houston, Kahn (2005) used satellite imagery to correlate increases in concrete/asphalt with substantial increases in runoff ratio in almost all major watersheds. This trend highlights the need for quantification of increases in flood risk associated with increases in urban development. This research seeks to measure the effects of historical development in northwest Houston and identify the spatial relationship between areas of land use change and areas of increased flooding. Predictions will then be made about the potential flood risk under future development scenarios, and vulnerable locations will be identified.

15. Statement of results or benefits:

The results of this study will provide valuable insight about the evolution of urban floodplains due to land use changes. By understanding the long-term spatial relationship between development and flood risk, urban planners and policy makers can make more informed decisions about development policies. Additionally, this type of research seeks to identify future areas of flood vulnerability and thus could motivate pro-active mitigation efforts. The results of this study for Cypress Creek could serve as a first step toward understanding the future of the watershed and the potential challenges it faces under continued development. **From this, long-term mitigation strategies can be designed and development policy can be amended to avoid increases in flood risk**. This work can also serve as an important case study for long-term urban planning since this research methodology could be implemented in numerous other urban watersheds.

16. Nature, scope, and objectives of the project, including a timeline of activities:

This study seeks to quantify the impacts of urban development and changing land use conditions on riverine flood risk in the Cypress Creek watershed (located in northwest Houston, Texas), and assess potential increases in floodplain extent resulting from projected land use changes.

The scope of this study will focus on the Cypress Creek watershed, which is a partially developed urban watershed located in northwest Houston. This watershed has seen rapid commercial and residential development trends in the last few decades and these trends are expected to continue based on land use projections for 2040. Due to the morphology and capacity of Cypress Creek and its tributaries, this

watershed is already vulnerable to riverine flooding, and Cypress Creek routinely over-tops its banks during moderate rainfall events. Currently, the upper portion of the watershed is comprised of mostly farmland and prairie, but substantial residential development is predicted to occur in this area over the next several years. Future increases in impervious cover resulting from development could substantially exacerbate flood risk in all portions of the watershed. This watershed serves as an important case study in storm water management since many Texas cities are growing rapidly and may face similar conditions in the future.

Specifically, the following research questions are posed:

I. What impact have historical land use changes in Cypress Creek had on the 100-yr floodplain and observed residential flood damages?

II. What is the spatial relationship between areas of land use change and areas of increased flood risk? Specifically, does land development negatively impact downstream communities by increasing their flooding potential?

III. Based on future land use projections, can potential increases in floodplain extent be predicted and can vulnerable areas of the watershed be identified?

**Timeline:** Mar-Jun 2017: Hydrologic and hydraulic analysis of historical land use changes and development of evolving 100-yr floodplain
Jun-Aug 2017: Development of potential future 100-yr floodplain resulting from predicted future land use conditions
Aug-Sept 2017: Spatial analysis of land use change vs flood risk increases for different frequency storms (10-yr, 50-yr, 100-yr, etc)
Sept-Dec 2017: Finalizing results and report writing

## 17. Methods, procedures, and facilities:

This study is comprised of three main components: hydrologic analysis, hydraulic analysis, and floodplain mapping/flood risk assessment.

**Hydrologic analysis methodology:** In order to quantify the stormwater runoff from a rainfall event, the distributed hydrologic model Vflo will be used. This software is developed by Vieux & Associates, and simulates rainfall runoff based on land cover, soil type, and elevation information. Historical land use data will be input to Vflo to quantify changes in runoff resulting from a 100-yr storm (as well as other frequency level storms). Projected land use data for 2040 will be used to simulate future increases in peak flows and runoff volumes in Vflo. Methodologies for calibrating and using Vflo are well documented in Fang et al (2010), Teague et al (2013), Doubleday et al (2013), etc.

**Hydraulic analysis methodology:** The surface runoff generated in Vflo will be input to HEC-RAS, which is a software that calculates water surface elevations in a river or stream. A steady hydraulic analysis will be conducted to quantify the maximum water surface elevations along Cypress Creek for each land use condition. The Cypress Creek HEC-RAS model used in this study is obtained from Harris County Flood Control District (HCFCD) and will be calibrated based on two recent storm events.

**Floodplain mapping/Flood risk assessment**: The mapping tool Arc-GIS will be used to model inundation resulting from the maximum water surface elevations. Flood impacts will be analyzed in Arc-GIS using parcel data and historical 311 flood calls. The spatial relationship between land use change and floodplain increases will be qualitatively assessed and quantitatively measured using geospatial methods in GIS.

18. Related research:

Land Use Change: Numerous studies have been conducted to investigate the impacts of land use changes in highly urbanized areas. In the Houston region a 2005 study by Khan investigated the link between increases in developed land and increases in overland and channel flow. He correlated increasing development with increasing basin yield (the percent of rain that becomes runoff at the outlet of the watershed), and concluded that areas of higher development experienced increasing basin yields. Other studies relating increases in development to increases in peak flows include Shi et al (2007), Hundecha & Bardossy (2004), and Niehoff et al (2002). More broadly, several studies have attempted to quantify regional land use changes using historical aerial imagery or remote sensing: Dewan & Yamaguchi (2008), Xiao et al (2006), and Weng (2002). While there have been many studies relating land use change to flow increases, there is not as much literature regarding the impacts of land use change on the floodplain. Increases in flows are not always directly translated to increases in floodplain extent since the floodplain determined by numerous other factors, including channel storage and roughness, watershed slope, existing detention, etc. However, in order to assess evolving flood hazard it is necessary to analyze changes in floodplain extent in addition to flow increases.

Hydrologic/Hydraulic Modeling of Flooding: Distributed hydrologic models have gained popularity in the past decade compared to more simplistic lumped models because of their ability to represent land use conditions and land cover more accurately. The Vflo software has been successfully utilized and calibrated in numerous other studies: Fang et al (2010), Teague et al (2013), Doubleday et al (2013). The software allows land use analysis to be conducted at the grid-cell scale rather than at the subwatershed or watershed scale. Generally, there have been many studies validating the usefulness of distributed models for flood simulations and flood risk forecasting. These include Looper & Vieux (2012), Kim et al (2008), and Vieux et al (2004).

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19. Training potential.

It is estimated that this project will train one Masters student (Avantika Gori), and one undergraduate student that will be hired Summer 2017.

20. Investigator's qualifications. See attached Resumes for both PI's.