TWRI Pre-Proposal Application

Which Program are you applying for? USGS Research Program

1. **Title of Pre-Proposal:** The impact of climate conditions on the urbanization-runoff process and implications for low impact development
2. **Student Information:**
Wonmin Sohn, Ph.D. student in the Urban and Regional Sciences program
Department of Landscape Architecture and Urban Planning, Texas A&M University
Degree starting year: 2015; Expected year of graduation: 2019
Email: wonmin.sohn@tamu.edu; Telephone:
3. **Advisor information:**
Ming-Han Li, Ph.D., PE, PLA, Professor
Department of Landscape Architecture and Urban Planning, Texas A&M University
Email: minghan@tamu.edu; Telephone:
4. **These funds would be:** initiating new research
5. **Abstract:**

Climate change has limited the capacity of the environment to be resilient to urbanization. Greater climate variability is also observed all over the world including Texas. With growing uncertainty in climate predictions, increased and connected impervious surfaces in cities speed up the conveyance of urban runoff which can cause severe flooding in downstream low-lying areas. Although the relationship between impervious surface and runoff is well documented in the literature, the impact of changing climate on urban runoff remains unclear. This study will examine how development patterns and levels of hydraulic connectivity are sensitive to climate characteristics through year-long and event-based monitoring of rainfall-runoff data. The study area will be three MSAs in Texas. The monitoring period includes 2011, 2013, and 2015 which were dry, temperate, and wet years, respectively. Five events with different storm intensities and durations will be selected through frequency analysis of historic rainfall data for event-based study. For each monitoring year and storm event, statistical models will be developed to identify the relationship between development variables and runoff yields. This study aims to strategically control hydrologic impacts of development under various climate conditions and promote applications of LID systems for mitigating frequent floods recently seen in Texas.

6. **Description of the student's proposed research:**

a. *Statement of Critical Regional or State Water Problem*

The populations of the selected three MSAs, including Houston-The Woodlands-Sugar Land, San Antonio-New Braunfels, and Austin-Round Rock MSAs, were 6.8 million, 2.5 million, and 2.1 million, respectively in 2016. From 2010 to 2016, they were ranked 15th, 20th, and 2nd of population growth out of 388 MSAs in the USA [1]. With increasing population density and impervious surfaces, urban flooding has become one of the major concerns for watershed protection in the study areas [2, 3]. To mitigate increasing waterlogging hazards, low impact development (LID) techniques appear to be a promising adaptation strategy which facilitates on-site infiltration and evapotranspiration by imitating a hydrological regime of pre-development [4]. However, efficiency of LID performance varies by storm characteristics such as intensity, duration, peak ratio, and initial soil moisture content. Prior studies found that LID systems performed better with a lower storm intensity, shorter duration, and lower initial soil moisture (longer dry periods) in extending lag time, reducing peak flow, and increasing retention rate [5-9]. Also, stormwater management facilities are designed to meet standards of historic performance using outdated storm intensity data [10, 11]. It is questionable whether they can still respond to changing climate conditions such as increasing storm intensity and frequency.

Expanded impervious cover also limits infiltrability of soil and caused groundwater deficiency. Ironically, in contrast to increasing flooding hazards during wet periods, a growing frequency and increased intensity of extreme drought has threatened Texas with severe reduction in groundwater recharge and surface water supplementation [12]. During dry years, reduced soil infiltration in urban areas and excessive withdrawals of groundwater could lead to land subsidence. For example, some regions in the Houston-Galveston MSA are expected to experience sinking land of ten feet in the next century due to severe groundwater deficiency [13].

Some local regulations, such as restricting impervious coverage by land use type [14] and charging drainage fees by property lots [15, 16], have currently been designed to decrease risks of natural hazards caused by urbanization and climate change. However, regulating only the total amount of impervious surface can lead to overestimation of impervious impacts on runoff yields. Furthermore, different climate conditions affect the conveyance capacity of impervious surfaces to generate urban runoff. Lacking knowledge of holistic systems of urban drainage under changing climate conditions would hinder local planners, policy-makers, and water resource managers to strategically control runoff for targeted storm events.

b. *Nature, Scope and Objectives of the Research, including a timeline of activities*

Nature: This study expands the current knowledge of climate impacts on the urban rainfall-runoff process. The process of development drainage examined in this study could be translated into two hydrologic systems: 1) the configurational interactions among development patches which regulate the pattern of overland flow, and 2) the connectivity of impervious surface to piped systems which controls hydraulic flow. Thus, the findings in this study will offer a better understanding of the holistic mechanism of development drainage and its sensitivity to climatic factors.

Scope: The spatial scope of this research is limited to watersheds located within three MSAs in Texas, including Houston-The Woodlands-Sugar Land, San Antonio-New Braunfels, and Austin-Round Rock MSAs. Over a hundred watersheds will be delineated based on streamflow data obtained from USGS gauge stations and national elevation datasets (NED) retrieved from the Texas Natural Resources Information System (TNRIS) by using Arc Hydro. The temporal scale will be 2011, 2013, and 2015 for year-long monitoring and five short-term events during the three years for event-based monitoring.

Objectives: The major objectives of this study are as follows:

- Examine how year-long climate conditions such as a wet, temperate, or dry years affect the relationship between development patterns and stormwater runoff
- Examine how storm characteristics such as high intensity and long duration affect the relationship between development patterns and stormwater runoff
- Examine how total impervious surface (TIA) and directly connected impervious area (DCIA) behave differently in runoff yields when year-long and event-based climate conditions change
- Examine which development variables (configuration vs. composition) are more sensitive to changes in climate conditions
- Assess how the impacts of development vary by the level of hydraulic connectivity and green space patterns and understand what this implies for LID application under various storm conditions

Timeline of activities:

- March – April 2018: Literature review and data preparation
- May – August 2018: Storm frequency analysis and spatial measurement of development variables
- September – November 2018: Statistical model construction and analysis
- December 2018: Result interpretation
- January – February 2019: Project finalization and report writing

c. Methods, procedures and facilities

First, multiple regression models will be developed using development, climate, biophysical, and hydrological variables under each climate condition to predict development impacts on runoff yields for varying storm characteristics. The hydraulic connectivity of development will be determined based on high-resolution impervious surface data, closed and open drainage networks, and satellite image interpretation. To quantify spatial patterns of development, landscape indices for measuring development size, shape, isolation, and connectivity will be computed at a watershed level using FRAGSTATS software. As independent variables, daily mean and maximum streamflow obtained from the USGS gauge stations will be used to compute annual runoff depth per unit watershed area and mean daily peak flow at each watershed outlet. Event-based runoff data will also be extracted from the hydrograph of individual watersheds obtained from 15-minute streamflow data.

Second, sample watersheds will be grouped by the hydraulic connectivity level of impervious surface (the ratio of DCIA to TIA) and green space patterns (e.g., clustered or dispersed) using K-means cluster analysis. With the year-long monitoring data, multiple regression models will be developed for each group. The hydrologic response of a watershed group, which has a lower hydraulic connectivity level and a dispersed green space, will be particularly examined for LID implication (See Appendix A and B for conceptual research design and measurement of construct variables).

d. Statement of expected results or benefits

Expected results: The wet year is typically characterized by storm events of long duration, high intensities, or short dry periods. Very limited studies have examined how the impact of development composition and configurations on runoff conveyance differs by storm conditions. With regard to development composition, it is expected that the impact of TIA on total runoff depths increases, while that of DCIA decreases in a wet year. Yao et al. [17] found that TIA contributes more to runoff volume than DCIA during heavy storms because of growing roles of disconnected TIA. When a rainfall exceeds a certain threshold, a pervious surface no longer absorbs runoff but rather acts as an impervious surface [18]. Thus, runoff produced from disconnected TIA flows into storm inlets with little loss and contributes to increasing total runoff volume [17]. Conversely, TIA will contribute less for frequent storms with longer dry periods, as increasing runoff from disconnected TIA will still be controlled by pervious areas. Instead, DCIA will be the dominant factor for generating runoff.

Similarly, it is expected that the contribution of the development pattern increases for intense storms or a wet year. The larger and more connected impervious surface with less patch-to-patch distance tends to increase runoff conveyance [2, 19]. It is possible that peak flow is more responsive to the development pattern than runoff volume with increasing storm intensity because increasing capacity of stormwater flow through a connected impervious surface may shorten travel time for runoff.

Overall, for the three-year monitoring period, urbanized watersheds with lower hydraulic connectivity and more dispersed green space will produce fewer runoff yields. They are also expected to be less sensitive to changes in climate conditions until the pervious surface becomes saturated and acts as an impervious cover for large storms.

Benefits: The event-based and year-long analyses performed in this study will help to understand how urban drainage systems are susceptible to changes in climate conditions at varying temporal scales. The quantitative relationship found in this study will offer an efficient tool for local planners to develop different stormwater management strategies for areas suffering from frequent or infrequent storms. For example, the more fragmented development form and lower imperviousness level will be required for 100-year floodplains. Conversely, control of hydraulic connectivity of impervious surfaces would be more efficient for areas subject to flash floods from frequent storms. Depending on the specific goals of mitigating the level of hydraulic connectivity, different types and number of LID practices can be applied.

7. **Budget:**

a. Specific funding needs: Tuition support (students' fee) and other costs (salary, fringe, travel, other)

b. Proposed use of funds by category

Category	**Request**	**Justification**
Salary	$ 3,000	Includes 260 hours of data analysis and 40 hours of field assessment
Travel	$ 500	Includes field investigation for 5 days
Tuition	$ 1,500	Includes students' fee
Total	**$ 5,000**	

c. Matching funds of 2:1 are required: Graduate teaching assistantship (9 months): $10,000

8. **Intended career path the student anticipates pursuing:** As an academic scholar and a professor of the future, I hope to provide students, developers, engineers, government agencies and citizens with critical paradigms on how the hydrological systems of current cities, which seem to be livable, are blind to changing climate conditions.

Appendix B. Construct variables, data source, and analytical tools

Construct	Variables (Acronym)	Formula[a]	Units (Range)	Source; Analytical tools
Dependent variable				
	Runoff depth		mm/unit watershed area	USGS
	Peak discharge rate		m^3/s	USGS
	Time to peak		min	USGS
Independent variables				
Development composition				
	Total impervious area (TIA)		%	Local government agency & TNRIS; ENVI & ArcGIS
	Directly connected impervious area (DCIA)		%	TIA & drainage network; ArcGIS
Development configuration				
Size & Edge	Mean patch area (AREA_MN)	$\sum_{j=1}^{n} a_{ij} \Big/ [n_i \cdot (10{,}000)]$	ha	TIA; FRAGSTATS
	Edge density (ED)	$\left[\sum_{j=1}^{n} e_{ij}/A\right] \cdot (10{,}000)$	m/ha	TIA; FRAGSTATS
Shape	Mean shape index (SHAPE_MN)	$\sum_{j=1}^{n} \frac{.25\, p_{ij}}{\sqrt{a_{ij}}} \Big/ n_i$	None (MSI≥1, without limit)	TIA; FRAGSTATS
Isolation	Mean Euclidian nearest-neighbor distance (ENN_MN)	$\sum_{j=1}^{n} h_{ij} \Big/ n_i$	m	TIA; FRAGSTATS
	Patch density (PD)	$\frac{n_i}{A} \cdot (10{,}000) \cdot (100)$	Count/100ha	TIA; FRAGSTATS
Connectivity	Patch cohesion index (COHESION)	$\left[1 - \frac{\sum_{j=1}^{n} p_{ij}}{\sum_{j=1}^{n} p_{ij} \cdot \sqrt{a_{ij}}}\right] \cdot \left[1 - \frac{1}{\sqrt{Z}}\right] \cdot (100)$	None (0 < COHESION<100)	TIA; FRAGSTATS
	Area-weighted radius of gyration (GYRATE_AM)	$\sum_{j=1}^{n} \left[\left(\sum_{r=1}^{z} \frac{h_{ijr}}{z}\right)\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right)\right]$	m	TIA; FRAGSTATS
Climate variables				
	Precipitation		mm	NOAA - NWS; NOAA Weather and Climate Toolkit & ArcGIS
Biophysical variables				
	Normalized Difference Vegetation index (NDVI)		None (-1≤NDVI ≤1)	USGS; ArcGIS
	Width of filter strip		m	TNRIS; ArcGIS
	Soil permeability		mm/hour	NRCS - STATSGO; ArcGIS
	Slope		%	TNRIS; ArcGIS
	Watershed area		km^2	TNRIS; ArcGIS

Note. n_i = number of patches in the landscape of patch type (class) i; a_{ij} = area (m^2) of patch ij; e_{ij} = total length (m) of edge in p_{ij} = perimeter of patch ij; h_{ij} = distance (m) from patch ij to nearest neighboring patch of the same type, based on edge-to-edge distance; A = total landscape area (watershed area in this study) (m^2); Z = total number of cells in the landscape

[a] See McGarigal and Marks [20] for more details.

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