A Multiplex approach to integrate social vulnerability into urban flood mapping

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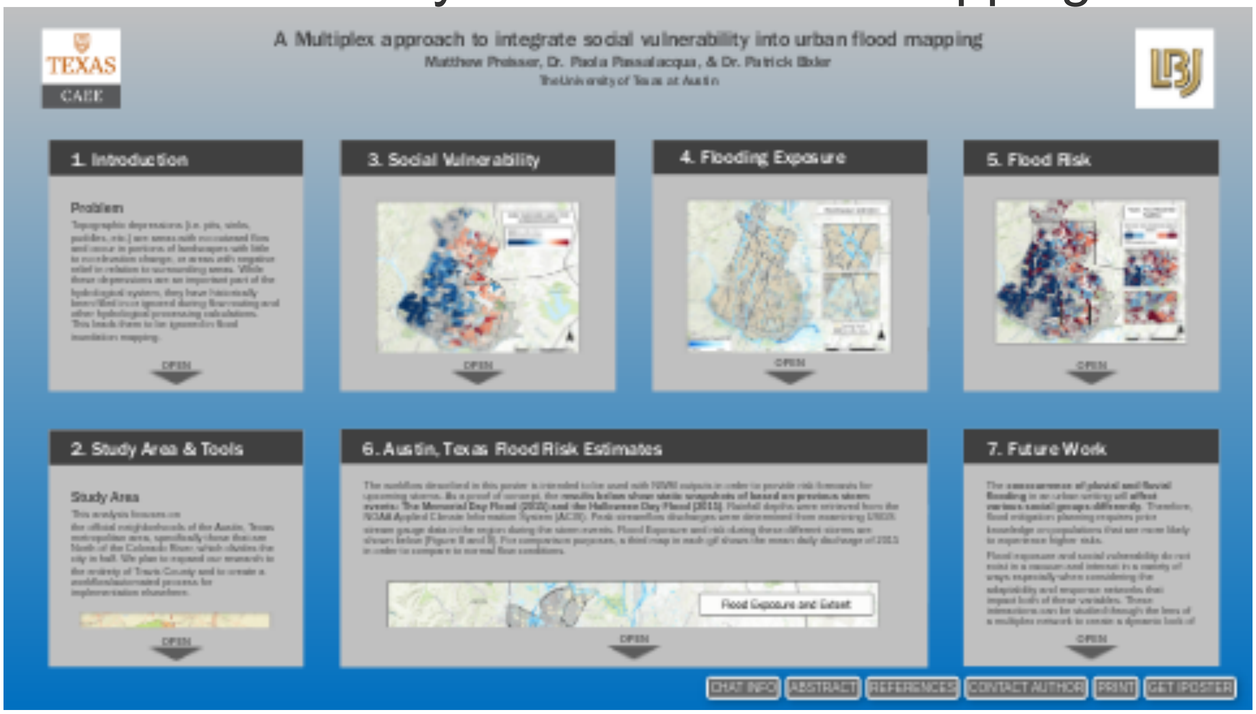
Abstract

Depressions are topographic areas that have no outward flow and occur in portions of landscapes with little to no elevation change, or areas with negative relief in relation to surrounding areas. While these depressions are an important part of the hydrological system, they have historically been filled in or ignored during flow routing and other hydrological processing calculations. With the increased prevalence of high-resolution topography data, understanding and evaluating how topographic depressions can impact overland flow is vital for improving hydrological analyses, specifically in the context of flood inundation mapping. Flooding caused from the filling of depressions (pluvial flooding) can have compounding effects when simultaneously occurring with river (fluvial) or coastal flooding. Our goal is to consider both pluvial and fluvial flooding in flat urban environments to identify areas that are significantly more vulnerable to inundation as compared to flood mapping from only one particular source. Our approach relies on a multiplex network that utilizes the Height Above Nearest Drainage (HAND) method as well as a hydraulic head equalization algorithm to estimate inundation patterns. Social vulnerability data are integrated in this framework to identify urban hot spots, defined as areas with a lower relative socioeconomic status in conjunction with a higher probability of inundation. Combining technical and social information leads to the identification of communities that are more vulnerable to the physical, economical, and social components of floods. This approach can help urban flood planners associate social disparities in relationship to flood preparedness and response.

A Multiplex approach to integrate social vulnerability into urban flood mapping



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The University of Texas at Austin

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1. INTRODUCTION

Problem

Topographic depressions (i.e. pits, sinks, puddles, etc.) are areas with no outward flow and occur in portions of landscapes with little to no elevation change, or areas with negative relief in relation to surrounding areas. While these depressions are an important part of the hydrological system, they have historically been filled in or ignored during flow routing and other hydrological processing calculations. This leads them to be ignored in flood inundation mapping.

Motivation

With the increased prevalence of high-resolution topography data, understanding and **evaluating how topographic depressions can impact** overland flow is vital for improving hydrological analyses, specifically in the context of **flood inundation mapping.**

Question

How does **flooding exposure** (fluvial and pluvial) **intersect vulnerability** and how can this be effectively conveyed to stakeholders **in terms of risk**?

Goals

1. To consider both pluvial and fluvial flooding in flat urban environments to identify areas that are significantly more vulnerable to inundation as compared to flood mapping from only one particular source.
2. Combining technical and social information leads to the identification of communities that are more vulnerable to the physical, economical, and social components of floods.

3. SOCIAL VULNERABILITY

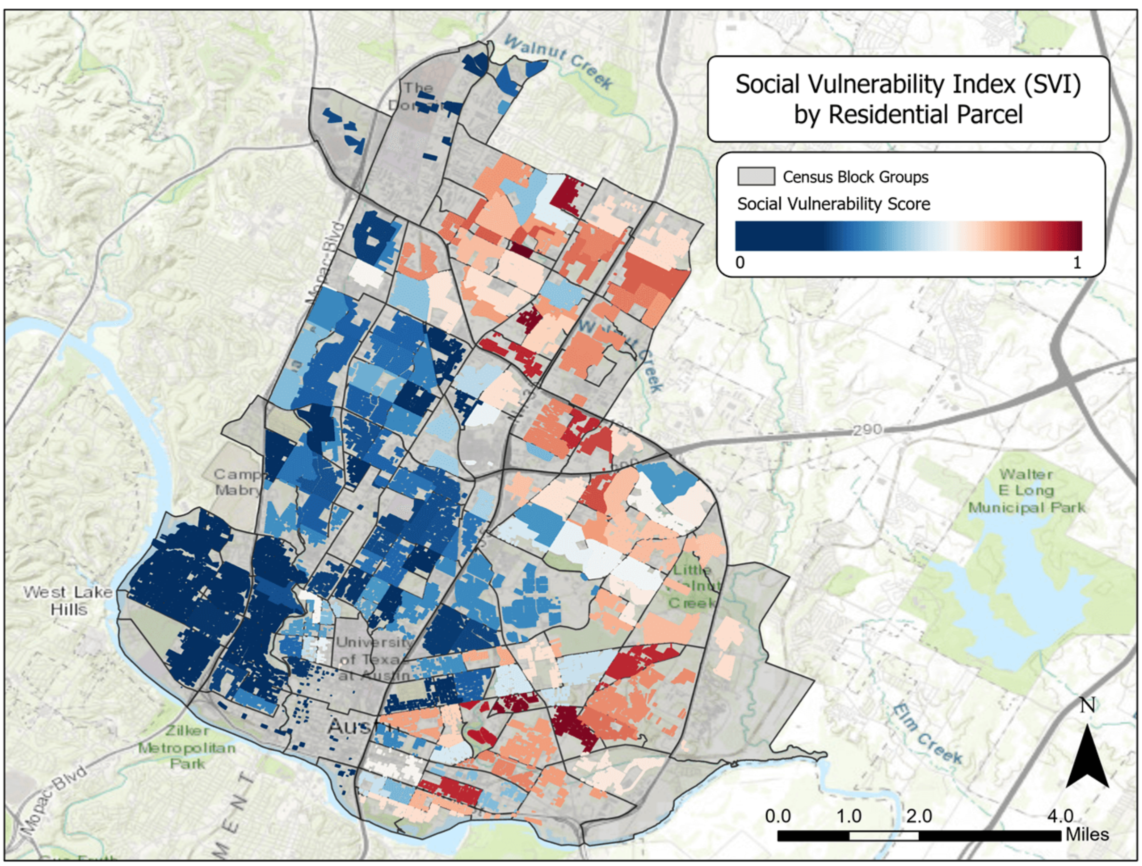

Figure 2: Social Vulnerability Index (SVI) by residential parcel for North Austin, Texas

Social vulnerability indices (SVIs) measure both the **sensitivity** of a population to natural hazards and its **ability to respond** to and recover from the impacts of a hazard. SVIs often rely on survey data, such as the **American Community Survey (ACS)** from the Census Bureau. Quantitative survey data is often aggregated at coarser resolutions than flood models. This is done to protect individual privacy and for strategic statistical sampling purposes to reduce the required input resources (time and money). The SVI of each BG was therefore dissolved and applied to each residential parcel, as shown in Figure 2 above.

This research utilizes an SVI produced specifically for Travis County, Texas and Texas at large (Bixler et al., 2020). The below workflow (Figure 3) outlines the procedure used to calculate SVI at the Block Group level for this particular study area. Following the principal component analysis, 18 variables were chosen for the SVI estimate, accounting for 74.48% of the total variance.

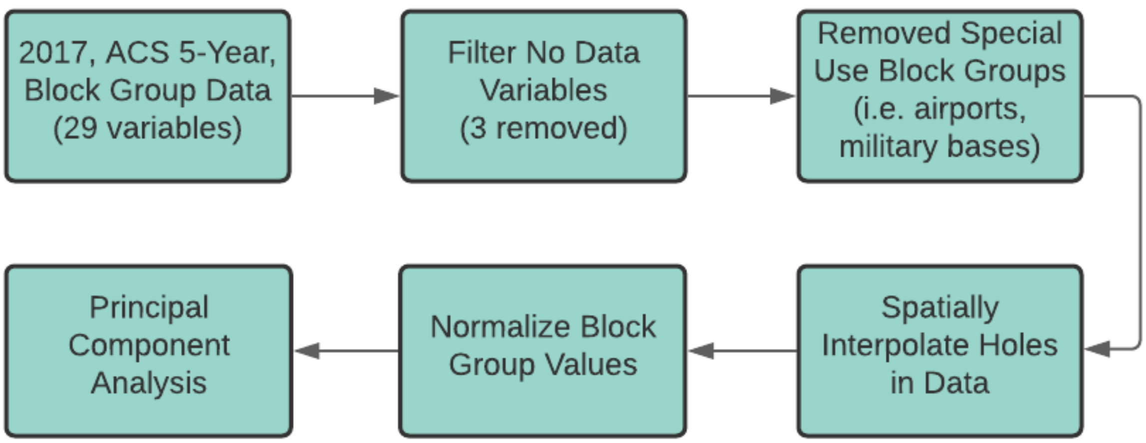

Figure 3: SVI workflow, as developed by Bixler et al., 2020

4. FLOODING EXPOSURE

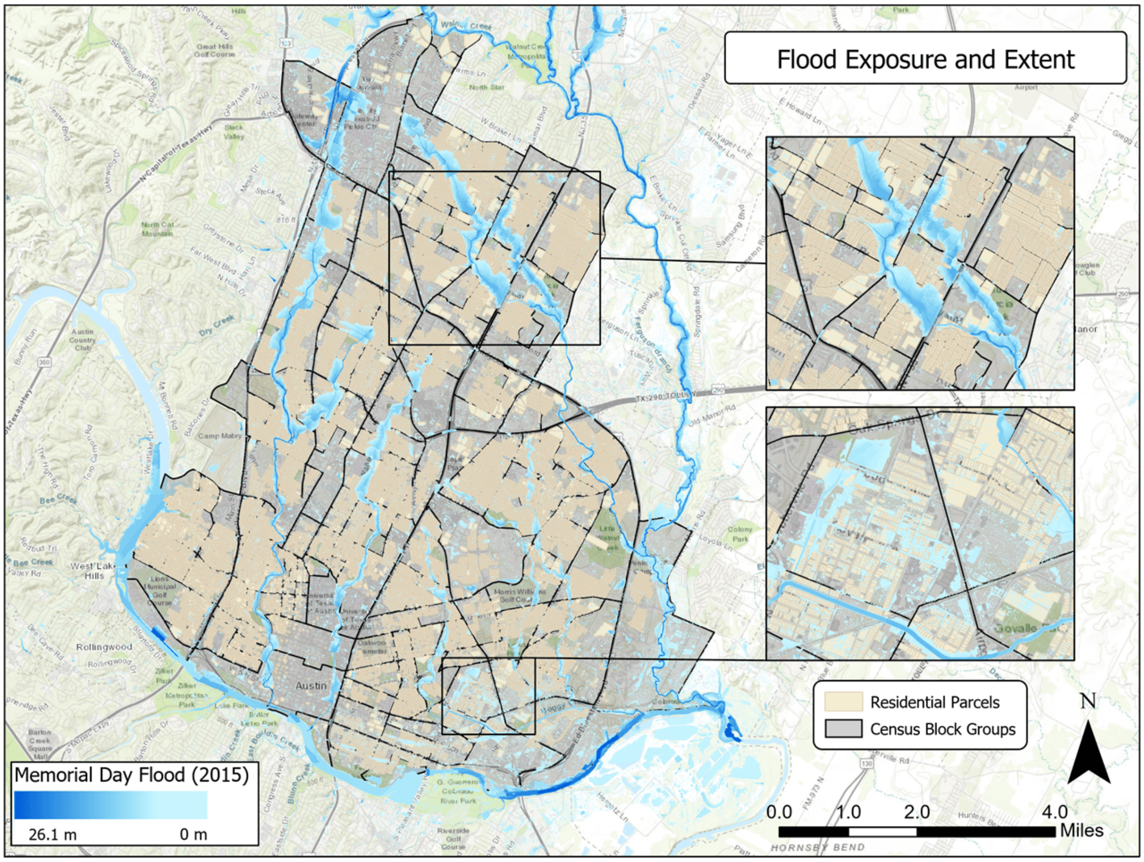

Figure 4: Flood exposure across North Austin, Texas, based on an estimated rainfall and discharge from the 2015 Memorial Day Flood

Prior to the recent increase in availability of Lidar data, **depressions in** coarser resolution digital elevation models (DEMs) **were filled** in and removed to ensure that water flowed continuously downstream as these **pits were seen as errors** in the data collection process. In reality, these are natural components of the landscape that affect surface hydrology.

Researching the identification, delineation, and connectivity of topographic depressions is just the first step in the application towards inundation mapping. Flooding caused from the filling of depressions (pluvial flooding) can have **compounding effects** when simultaneously occurring with river (fluvial) or coastal flooding. Figure 4 above shows the compounding nature of fluvial and pluvial flooding in our study region (based on the 2015 Memorial Day Flood).

Fluvial and pluvial inundation were determined through the following workflow (Figure 5), resulting in a single static event specific inundation layer.

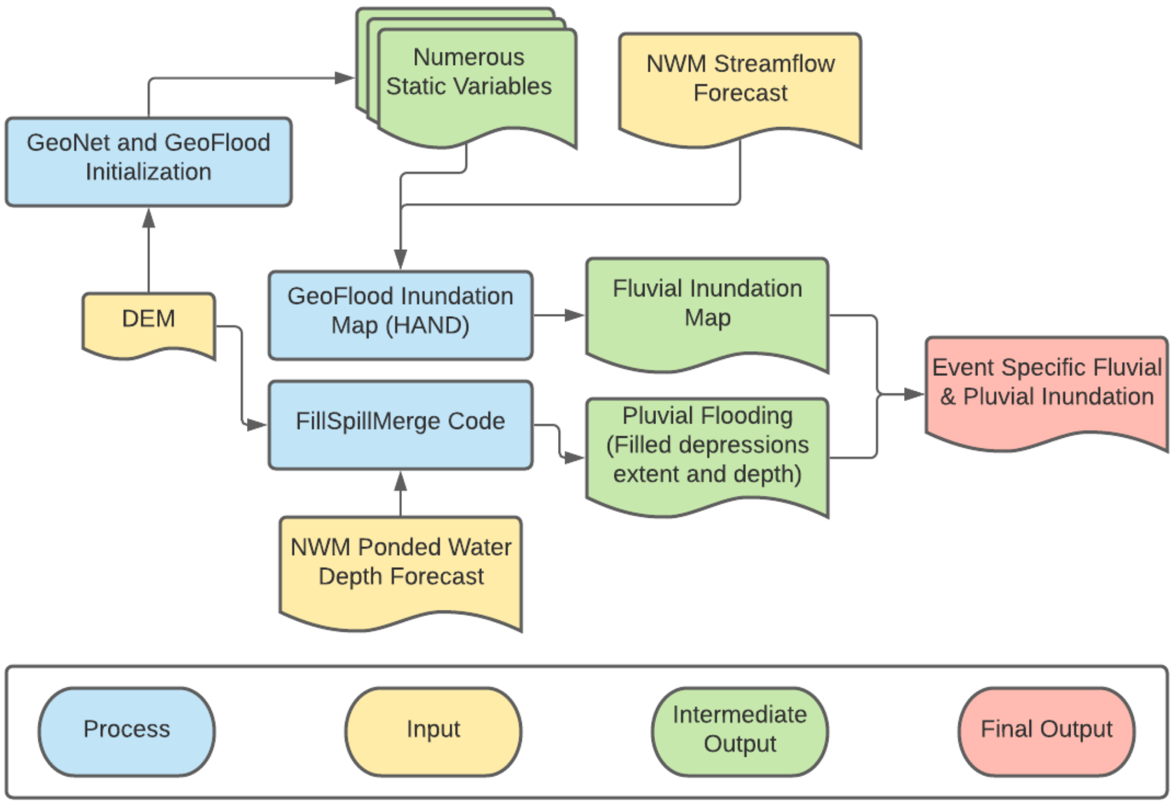

Figure 5: GeoNet and GeoFlood Workflow, as developed by Passalacqua et al., 2010

Pluvial Flooding: Using NWM ponded water depth (surface head) forecasts, water was routed over the surface (Barnes et al., 2020). The resulting layer shows the ponded water depth across the depressions.

Fluvial Flooding: The height above nearest drainage (HAND) is used to create a static inundation depth estimate based on forecasted stream flow.

Event Specific Inundation: Fluvial and pluvial inundation layers are merged or mosaiced into a single raster to show inundation over the study region.

5. FLOOD RISK

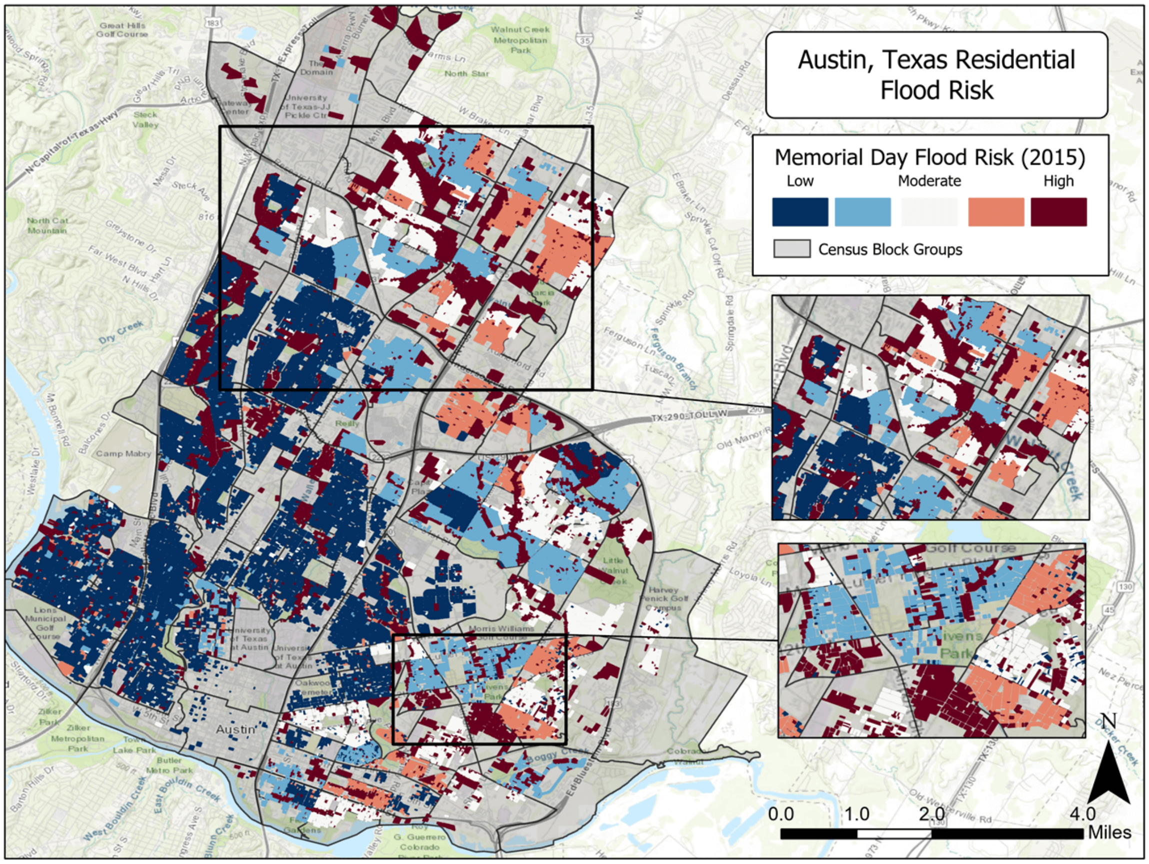

Figure 7: Flood risk across North Austin, Texas, based on an estimated rainfall and discharge amounts for the 2015 Memorial Day Flood

$$Risk = Vulnerability * Exposure$$

Risk is a function of vulnerability (SVI) and exposure (inundation). Areas that are **exposed more frequently** and with greater depths in conjunction with having **less resources to respond** to environmental stressors are at a **greater risk** relative to those who are not.

Due to the heterogeneity of populations that is often ignored in traditional flood risk management studies (i.e., aggregating results at the block group, zip code, or county level), this research focuses on dissolving variables to individual parcels (while maintaining an error estimation based on Census Bureau statistics). Figure 6 above shows the estimated risk at residential parcel levels (binned by quintile) for the 2015 Memorial Day Flood. The below workflow (Figure 7) details how this was accomplished:

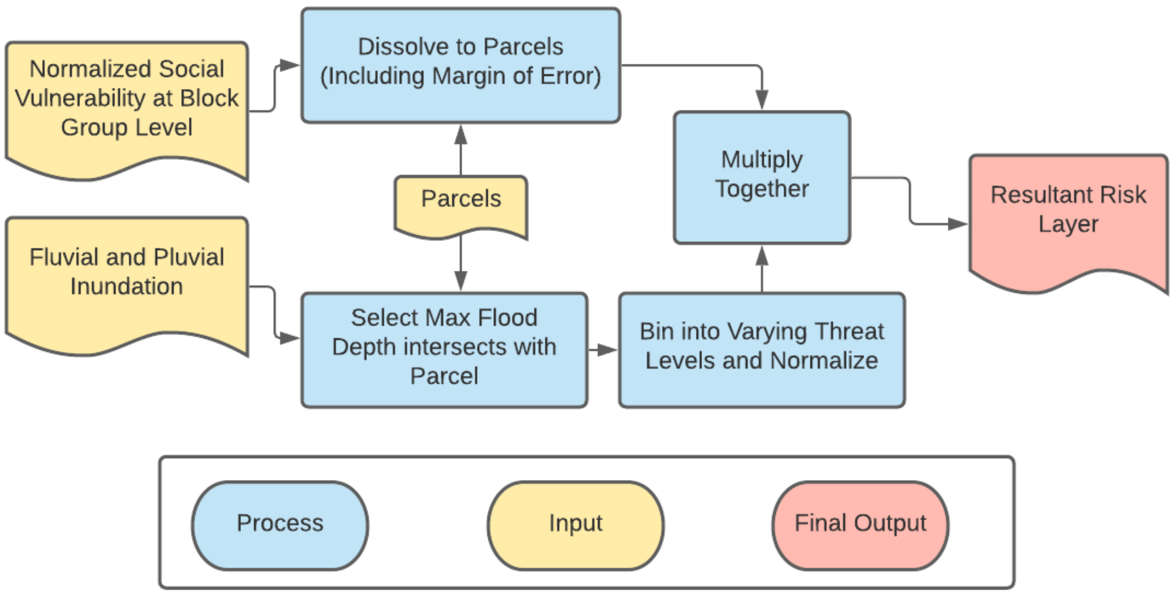

Figure 7: Workflow describing how SVI and flood exposure are combined at the residential parcel

In order to effectively communicate flood inundation threats, the below bins (Table 3) were created to define different exposure levels in easily understandable increments.

Table 3: Flood depth bins and their associated classification

Depth (m)	Description	Classification
0 m	No flooding	0
0.01-0.15 m	Ankle Deep	1
0.16-0.29 m	Lower than the Knee	2
0.30-0.49 m	Knee	3
0.50-0.91 m	Waist	4
0.92-1.07 m	Chest	5
>1.08 m	Higher than Chest	6

Flood Risk Estimates are shown and discussed in Box 6.

2. STUDY AREA & TOOLS

Study Area

This analysis focuses on the official neighborhoods of the Austin, Texas metropolitan area, specifically those that are North of the Colorado River, which divides the city in half. We plan to expand our research to the entirety of Travis County and to create a workflow/automated process for implementation elsewhere.

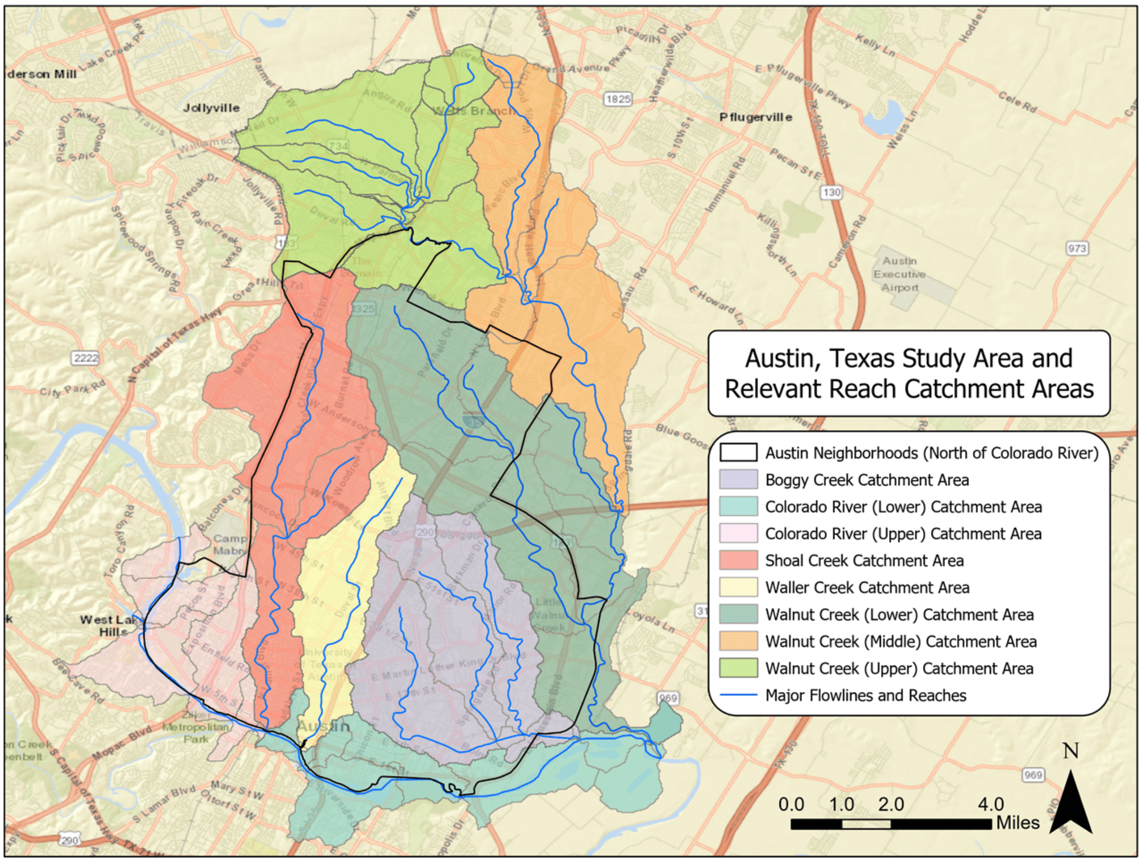

Figure 1: Study area of North Austin, with the delineated watershed boundaries and stream reaches covering this area

Resources

Below are tables of the tools and datasets utilized in this research:

Table 1: Tools utilized in this research

Tools	
Tool Name	**Purpose**
FillSpillMerge Barnes et al., (2020)	Taking estimated runoff as an input, this tool routes water over a landscape to fill topographic depressions (pluvial flood layer)
GeoNet & GeoFlood Zheng et al., (2018), Sangireddy et al., (2016), Passalacqua et al., (2010)	DEM processing that calculates height above nearest drainage (HAND) based on flowlines and given flow rate

Table 2: Datasets utilized in this research

Datasets	
Datasets	**Use**
1-meter DEM	Topographic Analysis
NWM: Channel Flow	Used in Fluvial Inundation Estimates
NWM: Ponded Water Depth	Used in Pluvial Inundation Estimates
Residential Parcels	Parcel Delineations
NHD Flowlines	Used in HAND Calculations
Social Vulnerability Index (SVI)	Social Vulnerability Estimates, Bixler et al., 2020

6. AUSTIN, TEXAS FLOOD RISK ESTIMATES

The workflow described in this poster is intended to be used with NWM outputs in order to provide risk forecasts for upcoming storms. As a proof of concept, the **results below show static snapshots of based on previous storm events: The Memorial Day Flood (2015) and the Halloween Day Flood (2015)**. Rainfall depths were retrieved from the NOAA Applied Climate Information System (ACIS). Peak streamflow discharges were determined from examining USGS stream gauge data in the region during the storm events. Flood Exposure and risk during these different storms are shown below (Figure 8 and 9). For comparison purposes, a third map in each gif shows the mean daily discharge of 2015 in order to compare to normal flow conditions.

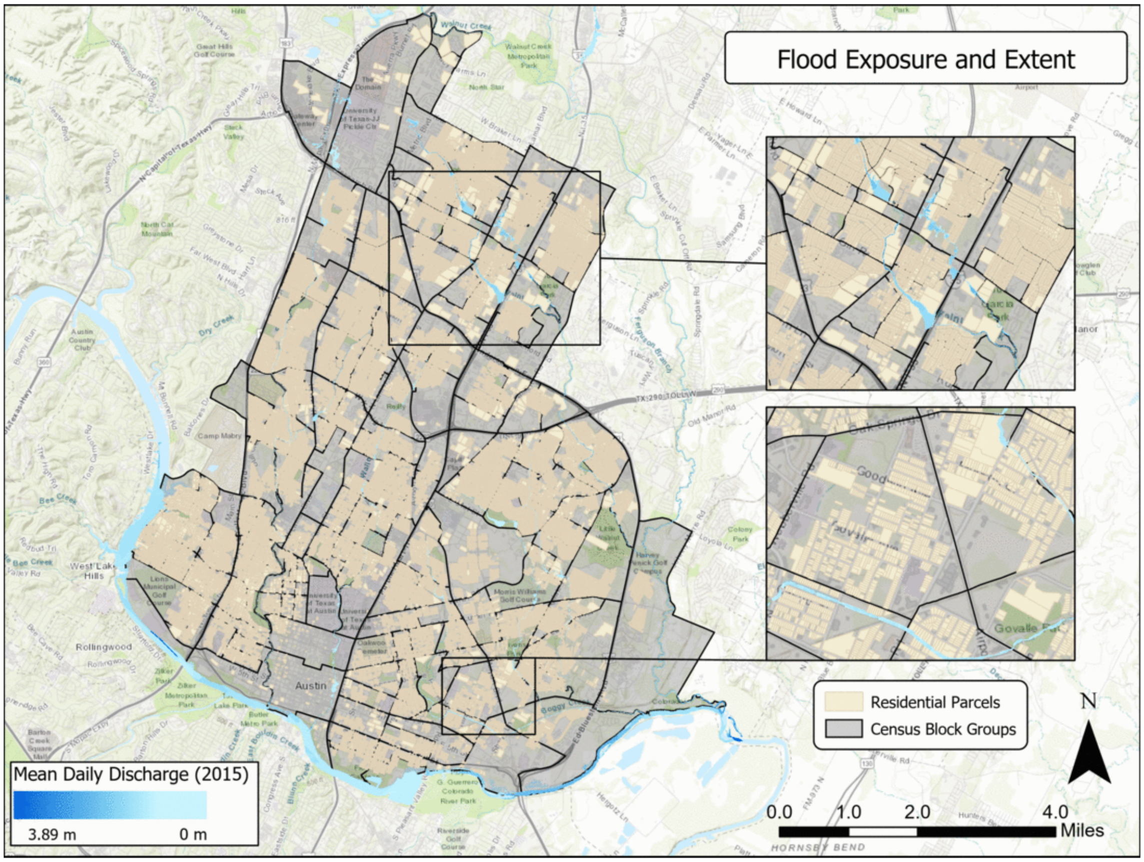

Figure 8: Flood exposure gif of mean daily discharge, the Memorial Day Flood, and the Halloween Day Flood (2015)

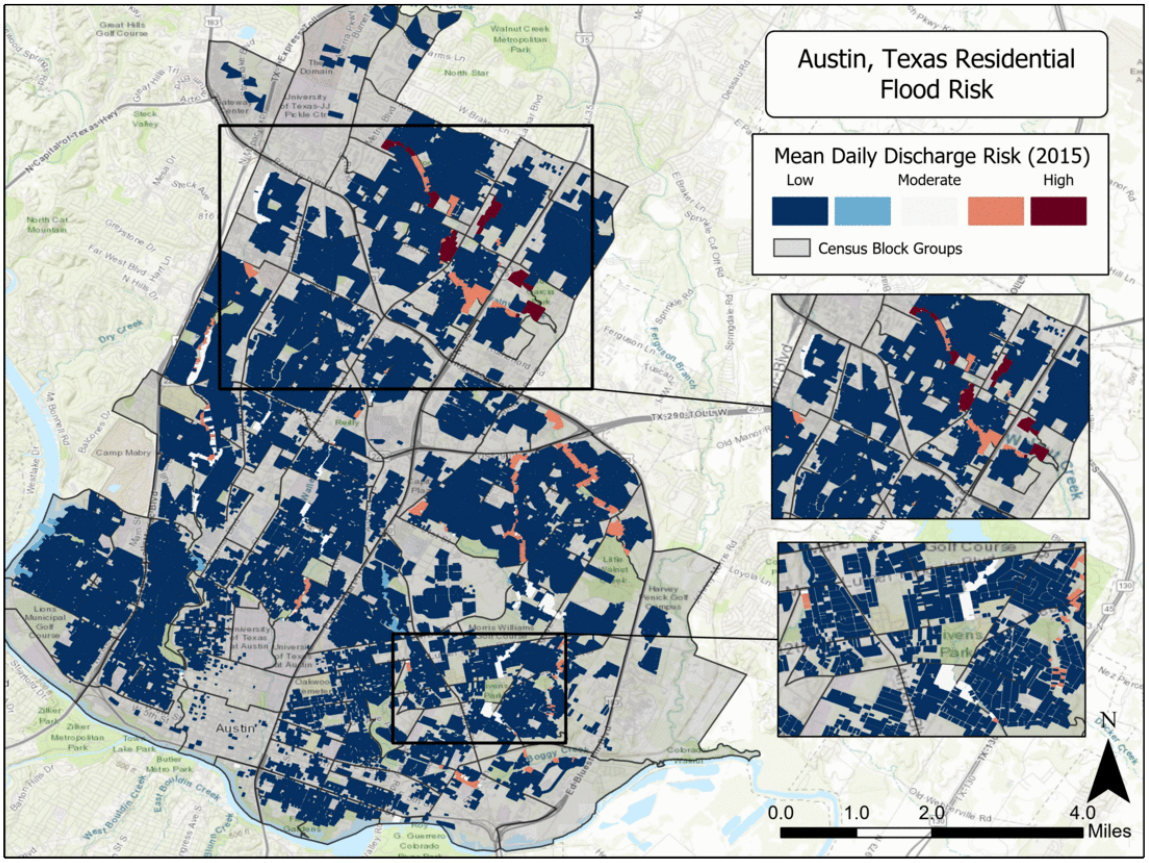

Figure 9: Flood risk gif of mean daily discharge, the Memorial Day Flood, and the Halloween Day Flood (2015)

These storms were chosen as they are often cited as some of the most recently devastating storms to affect Austin, Texas. The major takeaways and results are described below:

Results

Flood Exposure

- Figure 8 shows various flood exposure scenarios for two recent storms, and a daily mean discharge for comparison. This shows that flood extents, especially pluvial flooding is affects large portions of the study area, and flooding exposure is not limited to residential parcels adjacent to stream reaches.
- The map insets in Figure 8 show two different cases where fluvial or pluvial flooding is dominant. In the upper inset, inundation is prevalent along the stream reach, where in the lower inset inundation is coming from ponded water. This emphasizes the importance of considering both fluvial and pluvial flooding in inundation mapping, especially in urban settings.

Flood Risk

- Figure 9 shows the estimated flood risk, binned by quintile. It was binned by quintile to show the relative risk within the study region (i.e., a parcel's relative risk to another parcel). As can be seen under normal flow conditions (mean daily discharge) very few parcels are at risk of flooding. Analyzing the actual risk values and most parcels are 0 across the study region.
- When looking at each storm specific flood risk, the same general regions are highlighted orange and red suggesting that flood risk is relatively similar between these storms. However, there are some neighborhoods that vary and therefore emphasizes that risk is not a static variable and is storm dependent.
- Both map insets show that risk is variable within block groups. The upper inset shows that at risk residential parcels aggregate closer to stream reaches (can be seen in the long lines of red parcels that trace the location of reaches), while the lower inset suggests that risk can very more randomly as a result of pluvial flooding. Therefore, identifying high risk populations must be done at the highest resolution possible in order to account for this variability. Aggregating vulnerability, exposure, and risk to block groups, neighborhoods, or other boundaries will not identify local differences.

7. FUTURE WORK

The **cooccurrence of pluvial and fluvial flooding** in an urban setting will **affect various social groups differently**. Therefore, flood mitigation planning requires prior knowledge on populations that are more likely to experience higher risks.

Flood exposure and social vulnerability do not exist in a vacuum and interact in a variety of ways especially when considering the adaptability and response networks that impact both of these variables. These interactions can be studied through the lens of a multiplex network to create a dynamic look of risk in urban areas.

In the context of risk, we can update the previous risk equation to include **resiliency**, which includes factors such as public perception, capacity to adapt, reform, and respond, and impact on a community as a whole:

$$Risk = \frac{Vulnerability * Exposure}{Resiliancy}$$

Future questions that will be answered through this research include:

- How does fluvial and pluvial flooding impact road networks and accessibility?
- What role do sewer networks play in reduce flood exposure, particularly from pluvial flooding?
- Are their discernable changes to vulnerability and exposure over time?
- How can other social vulnerability variables be incorporated such as distance to critical resources (i.e., grocery stores, emergency response units, health services, etc.), community structure, risk perception?

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Depressions are topographic areas that have no outward flow and occur in portions of landscapes with little to no elevation change, or areas with negative relief in relation to surrounding areas. While these depressions are an important part of the hydrological system, they have historically been filled in or ignored during flow routing and other hydrological processing calculations. With the increased prevalence of high-resolution topography data, understanding and evaluating how topographic depressions can impact overland flow is vital for improving hydrological analyses, specifically in the context of flood inundation mapping. Flooding caused from the filling of depressions (pluvial flooding) can have compounding effects when simultaneously occurring with river (fluvial) or coastal flooding. Our goal is to consider both pluvial and fluvial flooding in flat urban environments to identify areas that are significantly more vulnerable to inundation as compared to flood mapping from only one particular source. Our approach relies on a multiplex network that utilizes the Height Above Nearest Drainage (HAND) method as well as a hydraulic head equalization algorithm to estimate inundation patterns. Social vulnerability data are integrated in this framework to identify urban hot spots, defined as areas with a lower relative socioeconomic status in conjunction with a higher probability of inundation. Combining technical and social information leads to the identification of communities that are more vulnerable to the physical, economical, and social components of floods. This approach can help urban flood planners associate social disparities in relationship to flood preparedness and response.

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