Assessment of the Growing Threat of Urban Flooding: A Case Study of a National Survey

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PREPARED FOR:

Urban Water Journal

PUBLISHED:

March 4, 2021

Urban Water Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/nurw20

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To cite this article: Jayton L. Rainey, Samuel D. Brody, Gerald E. Galloway & Wesley E. Highfield (2021): Assessment of the growing threat of urban flooding: a case study of a national survey, Urban Water Journal, DOI: 10.1080/1573062X.2021.1893356

To link to this article: https://doi.org/10.1080/1573062X.2021.1893356

URBAN WATER JOURNAL
https://doi.org/10.1080/1573062X.2021.1893356

CASE REPORT

Assessment of the growing threat of urban flooding: a case study of a national survey

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ABSTRACT

Urban flooding has become a national challenge in recent years due to a variety of socio-economic and environmental changes alongside rapid land use change in flood-prone areas. Losses from acute and chronic floods have become especially problematic in low-lying urban areas, where stormwater infrastructure deterioration, population growth, and development have accelerated over the last several decades. Unfortunately, limited information is available about the extent and consequences of urban flooding. In much of the country, little is being done to address these consequences and develop plans to address problems before they get worse. A nationwide survey was created and distributed to over 1,000 stormwater and floodplain management practitioners in both municipalities and organizations that work with municipalities. This study examines the responses from the distributed survey pertaining to what the main causes/drivers of urban flooding are and the mitigation strategies that are being currently implemented.

ARTICLE HISTORY
Received 15 April 2020
Accepted 4 February 2021

KEYWORDS
Urban flooding; flood mitigation; floodplain management; risk reduction; national survey

1. Introduction

Floods of all types present significant economic and social challenges in growing metropolitan regions globally and throughout the United States (US). Losses continue to accrue, and the potential impact of climate change and population increases are expected to accelerate the adverse impacts (Jiang, Zevenbergen, and Ma 2018; Mahmood et al. 2017; Melillo et al. 2014; Zhour, Su, and Ren. 2019). Recent Hurricanes Maria, Harvey, and Irma have only served to emphasize the magnitude of that floods pose to the nation and its economy. Primary attention has been focused on flooding that results from the overflow of rivers and from high water along coastlines as a result of sea level rise, tidal variability, and coastal storm surges. However, losses from acute and chronic floods have become especially problematic in low-lying urban areas, where storm-water infrastructure deterioration, population growth, and development have accelerated over the last several decades (Bertilsson et al. 2019). Much of this flooding occurs in more densely occupied urban areas, known as the built environment, where storm-water infrastructure is problematic. In the past, this type of flooding, known as 'urban flooding', was considered to have relatively minor impacts but has become increasingly more severe and difficult to assess.

The State of Illinois conducted a state-wide assessment on urban flooding in response to hundreds of millions of dollars lost throughout the Chicago metropolitan area between 2007 and 2014 (Winters et al. 2015). The assessment led members of Congress to question how this form of flooding exists across the nation. Texas A&M University joined with the University of Maryland to lead an exploratory study, a first of its kind, to address this concern.

Despite the growing challenge of urban flooding in the US, limited information is available about its extent and consequences, or what local jurisdictions are doing to respond to the problem. To address this knowledge gap, we conducted a representative survey of communities to establish a baseline on the state of urban flooding across the nation. Specifically, we aim to better understand: (1) the degree of impact and its location; (2) the major causes of the problem; (3) the mitigation methods being used to reduce flooding; and (4) the major obstacles preventing localities from implementing flood risk reduction measures. Survey findings reveal important aspects of urban flooding across the US and provide guidance to decision makers on how to effectively mitigate future impacts.

The following section provides a background on urban flooding and outlines the limited research done to date. Next, we present the research methods used in the study, including sampling frame, response rate, and variable measurement. Results describe the severity and extent of flooding from both a regional and national perspective. Interpretation of summary statistics leads to policy implications and insights for decision makers interested in mitigating urban flooding in the future. Finally, we note the limitations of the study and suggest future lines of research to address the problem.

2. Urban flooding as a growing threat in the US

Flood problems are traditionally associated with riverine and coastal areas, but increasing attention is being given to urban flooding, where flood risk is more a function of the human-built environment, such as buildings, roads, rooftops, parking lots, and public infrastructure (UMD/TAMUG 2018). Population

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Supplemental data for this article can be accessed here.

growth and associated development in metropolitan areas along the coast, combined with aging stormwater infrastructure and changing weather patterns, have given rise to an urban-specific flood problem of growing importance (Gori et al. 2019; Brody, Highfield, and Blessing 2015; Chavez and Krupa 2017; Craig 2017). In this newer category of flooding, risk and impacts are no longer tied to the FEMA-defined floodplains derived by analyzing stream channels or bayous. Instead, significant flood losses can also occur miles from a delineated floodplain where they are embedded in a highly developed landscape (Highfield and Brody 2013; Blessing, Sebastian, and Brody 2017; Lewis 2017). Given that the urban footprint in the US is predicted to increase from 3.1% to 8.1% from 2000 to 2050, especially in coastal regions, urban flood losses will continue to mount and present an important national policy problem for years to come (Nowak and Walton 2005).

This study considers urban flooding as impacts from inundation exacerbated or caused by the human-built environment. FEMA defines urban flooding as 'the inundation of property in a built environment, particularly in more densely populated areas, caused by rain falling on increased amounts of impervious surfaces and overwhelming the capacity of drainage systems. The definition excludes flooding in undeveloped or agricultural areas, but instead focuses on situations in which stormwater enters buildings through (a) windows, doors, or other openings; (b) water backup through pipes and drains; (c) seepage through walls and floors' (State of Illinois, Department of Natural Resources 2015). The definition has been expanded to include specific issues, such as sewer water backing up into homes, water seeping through foundation walls, clogged street drains, and overflow from sound walls, roads, or other barriers that restrict stormwater runoff. Urban flood loss related to the built environment is caused by multiple triggers; aging and inadequate drainage systems, failure to maintain drainage systems, sewage and stormwater backups, changes in overland flow conditions, and increases in local and region runoff.

The National Academies of Sciences, Engineering, and Medicine (2019) report, *Framing the Challenges of Urban Flooding*, states that urban flooding must be studied and understood across four dimensions: (1) Physical – both natural and built environments where development and infrastructure impact the ability of the system to drain, transport, and store stormwater runoff. (2) Social-impacts on people, property, business services, and household functionality. (3) Actions and Decision Making- flood mitigation techniques, both structural and non-structural that seek to reduce the risk and adverse impacts of floods. (4) Information- data analytics used to understand or communicate flood risk, such as inundation maps, demographics, federal claims and payouts, web decision tools, etc.

While infrequent major storm events and floods have created historic riverine and coastal disasters, urban flooding, which occurs frequently and ubiquitously, is difficult to measure systematically, especially at the national level. The total cost of urban flooding has not been accurately recorded or recorded at all for several reasons, including: (a) such floods occur frequently; (b) they are scattered in neighborhoods throughout communities; and (c) they do not rise in total economic costs to the level of major events or federal Disaster Declarations. Oftentimes, these events inflict significant economic and social damage on groups that have the least ability to deal with them.

Limited data that do exist indicate a national problem that is growing over time. For example, NOAA has maintained a flood loss database since 1993 constructed from regional field office reports that includes an urban flood category containing descriptive information about storm events, including damages reported by various sources so that estimates can be made of some of the losses attributed to urban flooding. Between 1993 and 2017, NOAA reported urban-based losses of over 17 USD million and 27 death based on 3,663 flood events (UMD/TAMUG 2018). Another national source of data that can be used to indicate urban flooding are FEMA National Flood Insurance Program (NFIP) claims and payouts, which is considered the most comprehensive and spatially specific information consistently recorded. As shown in Figure 1, most insurance claims made from 1972 to 2014 were located within a US Census-defined urban area, particularly outside of the FEMA-designated A, B, C, D, and V zones that make up the 100-year floodplain boundary. The area outside of the 100-year floodplain is known as the 'X-Zone'. The percent of claims in the X-zone has been increasing in number and distance from this boundary over time, indicating flood losses are increasingly attributed to conditions of the built environment. In Texas, for example, the percent of X-zone flood claims under the NFIP has gone from negligible in the mid-1980s to well over 50% by 2014 (GCRT 2018) (Figure 2).

Extreme events only serve to exacerbate the influence of underlying built environment characteristics. Following Hurricane Harvey, The Harris County Flood Control District in Houston, TX reported that 68% of flooded houses in the county were located outside of the 100-year riverine floodplain.

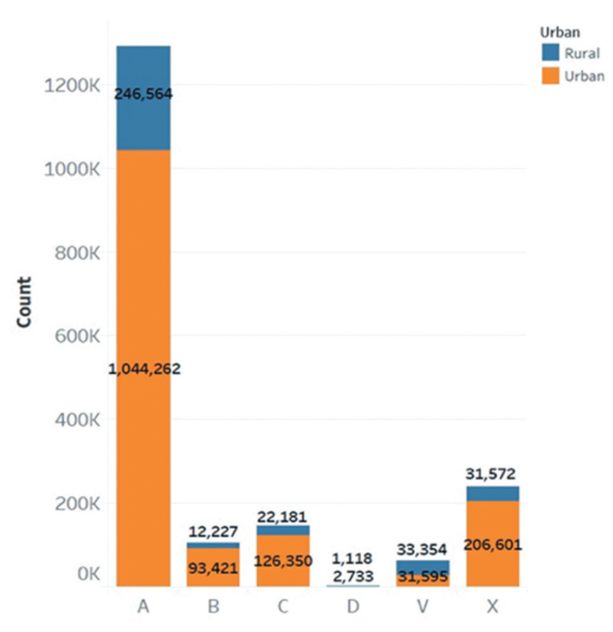

Figure 1. Total NFIP claims between 1972–2014 by FEMA-designated zone and urban/rural designation (2010 census).

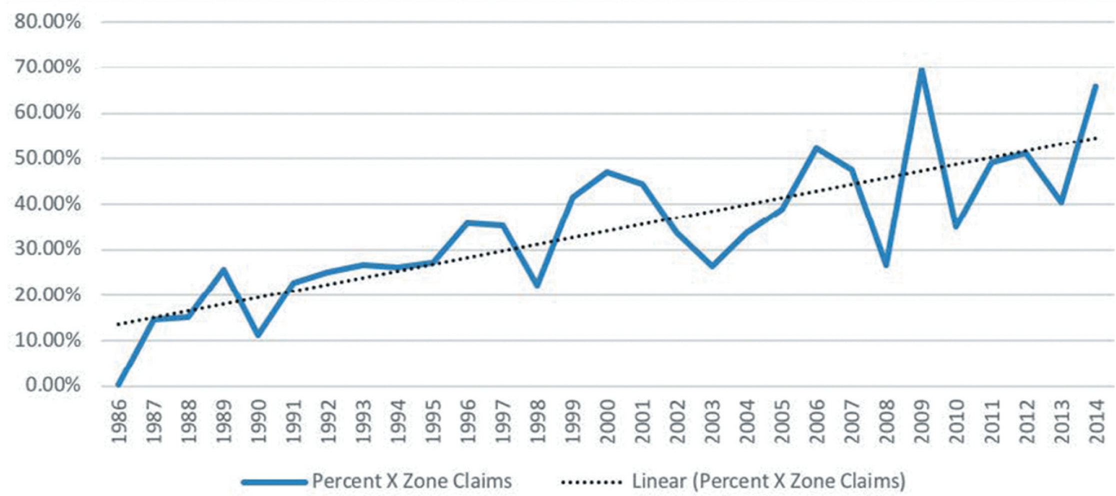

Figure 2. Number of NFIP flood claims located in the FEMA-designated X-Zone between 1986 and 2014.

Another notable case of urban flooding occurred in Cook County, Illinois where over 176,000 NFIP claims totaling 660 USD million were recorded from 2007 to 2011 alone. Seventy percent of 115 respondents to a survey conducted by the Chicago-based Center for Neighborhood Technology (CNT) indicated that they had flooded three or more times during this five-year period; 20% had flooded 10 or more times. The study found that 90% of the claims for flood damage in urban areas filed between 2007 and 2014 were for properties located outside of the 100-year floodplain and most likely represented urban flooding (CNT 2014).

Urban flooding occurs not just in major cities during catastrophic events, but in many US communities, large and small. For smaller communities, the impact is more severe because they frequently lack the resources to deal with significant rainfall events and, because of their size, do not rise to the level of losses associated with federally supported disaster assistance. Heavy rainfall during short time periods (such as recently seen in Washington, DC, Ellicott City, MD, Houston, TX, etc.) is often enough to flood roads, businesses, and disrupt public infrastructure even though these are not considered weather disasters.

3. Flood risk reduction and mitigation strategies

To effectively address the growing threat of urban floods across the US, communities will need to consider and adopt a range of different mitigation strategies working synergistically over time. These activities range from drainage infrastructure and elevation of structures to the protection of naturally occurring wetlands and techniques for risk communication (Brody and Atoba 2017). While the specific portfolio of flood risk reduction strategies put into place must depend on the unique characteristics of each local jurisdiction, it will draw from a common set of approaches that fall into the following four categories: Avoidance, Accommodation, Resistance, and Communication.

An *Avoidance* approach to reducing flood risk involves removing development or steering it away from the most vulnerable areas, such as the 100-year floodplain. While complete retreat may not be possible, the idea of avoiding specific flood-prone areas is gaining widespread acceptance. Avoidance can be vertical, elevating structures and people above anticipated flood levels; or horizontal, pulling back from or prohibiting construction in the most flood-prone areas. The most prominent structural technique to vertically avoid flood waters is the elevation of buildings on pilings or some other support structure. Communities participating in the NFIP already must elevate new residential buildings in a 100-year floodplain to or above the base flood elevation (BFE), the level flood waters are expected to reach in a 100-year flood. Elevation requirements can be costly, and difficult if the structure is a 'slab on grade' design (that is, a concrete slab poured over excavated soil). The upfront costs, however, usually are offset by avoided flood losses over time. For example, in a national study, Highfield and Brody (2013) showed localities adopting freeboard standards each saved about 800,000 USD in flood losses annually. Policies that focus on horizontal elevation are meant to guide or pull development away from vulnerable areas, such as coastlines, floodplains, or river-bottoms (Beatley, 2009). Strategies under this category of mitigation include both regulatory and incentive-based policies that can help facilitate more flood-resilient development patterns over the long term (Brody, Highfield, and Kang 2011).

Accommodation strategies allow or even encourage flooding in specific areas and under certain conditions. The idea is that communities can co-exist with periodic inundation and even provide a relief-valve when there is an excessive build-up of storm-water runoff. The most commonly used acceptance mitigation strategy is the placement of retention or detention ponds that collect, hold, and slowly release storm water. Retention ponds always contain water and store floodwaters by allowing them to infiltrate slowly, essentially artificial lakes. While retention ponds can add more value to a community, greater attention must be paid to maintaining proper water levels in them during heavy rains. In contrast, detention ponds usually are vegetated depressions hidden behind houses, possibly used as playing fields during dry periods. They hold water for a short time during flood events and usually remain dry at other times. Retention and detention ponds are most effective in well-planned communities where they can be strategically placed for maximum effect. Several studies across the US have documented the effectiveness of on-site detention in mitigating the impacts of urbanization. For example, a study across 31 watersheds in North Carolina and Virginia found that detention systems could partially mitigate peak-flow increases caused by urbanization (Mogollón et al. 2016). A study in Georgia reached similar conclusions (Aulenbach et al. 2017).

A third category of flood risk reduction is *Resistance*, which most often involves structural measures, such as large-scale building and construction projects that actively protect communities situated in vulnerable areas. This 'stand and fight' approach to flood risk reduction recognizes the importance of locating development in flood-prone areas for commerce, industrial production, recreation, and aesthetics. Initial flood mitigation efforts in the US focused on large-scale structural projects, such as levees and dams, beginning with the Mississippi River flood in 1927 (Birkland et al. 2003). Dams are the most ubiquitous resistance measure consisting of an artificial barrier usually constructed across a stream channel to impound or store water. Over 80,000 dams mark the American landscape, many serving multiple functions, such as recreation, water supply, and power generation (Graf 2001). These mitigation structures are very effective in modulating stream flows and shielding downstream coastal communities from flooding, but can result in reduced nutrient and sediment transport, channel obstruction, loss of floodplain area, and overall hydrologic fragmentation (Nilson and Berggren 2000). Also, failure of the dam or levee structure can generate a sudden catastrophic pulse of water and debris that inundates downstream areas (as has happened periodically since the 1800s).

A final category of flood risk reduction is *Risk Communication*. When residents understand the risks of flooding and how best to mitigate the adverse effects of storm events on their property, overall losses at the community level can be significantly reduced. Outreach projects that educate residents about the probability of inundation in and around the 100-year floodplain will help them make more informed decisions when purchasing new homes. Information about the various options available to mitigate flood impacts to households, from insurance purchase to dry-proofing basements, will help residents protect their investments. Both general and targeted outreach projects at the local level increase awareness and help residents make better decisions on protecting themselves from the impacts of future storms. Examples of outreach projects can be written materials, web content, and in-person workshops or training sessions. These can be used to explain hazard risk and reduction techniques to multiple stakeholders and the general public.

While each approach can have an individual effect, communities genuinely interested in flood mitigation must consider adopting programs where multiple techniques working synergistically to reduce flood losses. Comprehensive community flood risk reduction lies at the intersection of avoidance, accommodation, resistance, and communication. It is up to each community to decide their optimal portfolio of flood mitigation strategies based on specific local contextual characteristics and the amount of savings they want to accrue in the future.

4. Research methods

To gather information about the nature and extent of urban flooding, the study team developed a sampling frame of stormwater and floodplain management practitioners working in local municipalities and related organizations. E-mail surveys were administered to a sample of 1,000 individuals representing every state in the US. Over 700 individuals responded to the survey representing 48 states and 350 municipalities. Professionals in Wyoming and Montana who did not respond were subsequently contacted by telephone and given the survey to complete a nationally representative response on urban flooding. In addition, respondents provided 103 general comments on the topic as well as 883 comments or explanations to supplement answers to specific questions.

The average number of responses to non-demographic questions was 306; however, the same individuals did not answer every question. In listing survey results, the percentage of respondents providing a given answer is shown against the number of respondents who provided answers to that question (e.g. n = X). Survey questions pursued the following three overarching topics: (1) the extent and impact of urban flooding in local communities; (2) the triggers or drivers of the urban flood problem; and (3) the types of mitigation strategies being implemented at the local level. Descriptive summary statistics for each topic indicate the magnitude of urban flooding and its complexity from a national perspective.

In addition to reporting frequencies for individual survey questions, we created indices representing the total number of mitigation efforts selected by respondents under each flood risk reduction category previously mentioned (Table 1). The number of strategies selected for *Avoidance* was combined on a scale of 0–6 based on building codes that require reduced runoff, aquatic buffers, impervious surface reduction, watershed planning, property buyouts and building relocation, and building elevation (e.g. freeboard). The mean number of *Avoidance* strategies selected was 2.07. The *Accommodation* variable has a scale of 0–7 based on combining the mitigation strategies of new drainage systems, surface stormwater storage, underground stormwater storage (e.g. cisterns), on-site detention, bioswales, rain gardens, and installation of green roofs. *Accommodation* strategies were used slightly more than avoidance, with a mean score of 3.18. The *Resistance* variable has a scale of 0–6 based on combining back-up prevention gates, home retrofits (e.g., wet and dry-proofing), dams within the municipality, dams within watershed outside of municipality, levees/floodwalls, and paved channels. The six evaluated *Resistance* mitigation strategies received the least amount of use by localities responding to the survey, as evidenced by the mean score of 0.71. Lastly, a *Mitigation* variable index was calculated by combining all previously mentioned mitigation

Table 1. Summary statistics of each generated mitigation strategy index based on 317 respondents from the administered survey.

Mitigation Strategy	n	Mean	Std. Dev.	Minimum	Maximum
Avoidance	317	2.07	1.51	0	6
Accommodation	317	3.18	1.92	0	7
Resistance	317	0.71	1.09	0	6
Mitigation	317	5.95	3.53	0	19

items, creating a scale of 0–19. The mean number of selections made by the respondents for each mitigation strategy are detailed in Table 1. Chronbach's Alphas were calculated for each index to ensure sufficient scale reliability.

5. Results

5.1. Extent of impact

Survey results on the scope and impact of urban flooding show that it has become a widespread problem. Eighty-three percent of 385 respondents (Table S1) reported that their community had experienced urban flooding and 65% had been affected by moderate or larger flood events (Table S2). Of the 325 survey respondents reporting urban flooding impacts, 49% reported that the consequences of flooding were moderate or significant, but only 2% reported disastrous consequences (Table S2). Of 291 responding communities, 50% of those affected by urban flooding were residents with moderate-income status; approximately 20% were reported to be in the low-income group (Table S3).

In terms of locational impact, 46% of 323 respondents indicated that urban flooding occurred in numerous areas or most areas in these communities (Table S4). Eighty-three percent of 264 responding communities had experienced urban flooding outside the Special Flood Hazard Area (SFHA) boundary (Table S5). Because of these flooding patterns, 65% of survey respondents marked that under 10% of residences damaged by moderate urban flooding were covered by insurance under the National Flood Insurance Program (Table S6). This response increased to approximately 80% for commercial or non-governmental insurance (Table S7).

5.2. Drivers of flooding

The survey also asked respondents to identify the degree to which nine specific causes or drivers were most responsible for the urban flood problem in their community (Table 2). Inadequate or under-designed drainage infrastructure lacking proper maintenance was cited as the top cause of urban flooding at the local level. The age of the systems, by contrast was considered less of a problem (just over 40% of respondents). Sewer back-up (18%) and road obstructions (19%) were reported as even less problematic root cause of flooding.

On the other hand, there appeared to be a greater recognition of the impacts of more regional development patterns leading to changes in stormwater runoff. For example, over 55% of respondents noted increased runoff and 41% changes in runoff over time as major causes of urban flooding. Similarly, approximately 40% of survey participants considered upstream development as a driver of flood losses for downstream residents.

Table 2. Survey responses and percentages to the principal causes or drivers most responsible for urban flooding in their community based on the 320 respondents to this section.

Rank	Causes/Drivers	n	Percentage
1	Inadequate Drainage System	241	75.31
2	Increased Local Runoff	177	55.31
3	Development in Low Elevation Areas	147	45.94
4	Aging Infrastructure	134	41.88
5	Changes in Runoff Over Time	131	40.94
6	Upstream Development	126	39.38
7	Highway and Road Obstructions	63	19.69
8	Sewer Back-up	60	18.75
9	Groundwater Problems	59	18.44

5.3. Mitigation

Respondents were asked to select among 19 different mitigation techniques being used in their community to reduce flood impacts. Strategies were categorized along the three dimensions described above: avoidance, accommodation, and resistance. Table S8 depicts the total number of mitigation strategies selected by each respondent. Overall implementation of mitigation techniques from 317 respondents was low, with a mean response of 6 on a scale from 0 to 19. Approximately 85% of responses had an average score of 9 or below.

5.4. Avoidance

Building codes that require reduced runoff were the most prevalent mitigation strategy under this category, with 48% of communities reporting its use locally. Watershed planning to reduce flood impacts through development management also figured prominently among localities (43% adopted this measure). Vertical avoidance through structural elevation is also being relied upon to reduce adverse impacts from floods; approximately 40% of respondents noted the use of this mitigation technique. In contrast, aquatic buffers and property buyouts, two techniques often reserved for protecting natural functions, were rarely used for flood risk reduction (Table 3).

5.5. Accommodation

Traditional forms of water collection and storage were reported most regularly, such as stormwater storage at the surface (62%), on-site detention (72.5%), and overall drainage system planning (58%). By comparison, site-specific techniques implemented by individual homeowners or developers, such as bioswales (39%), rain gardens (39%), and green roofs (11%) were reportedly used far less regularly at the jurisdictional level (Table 4).

5.6. Resistance

Structural solutions, such as sewer back-up prevention devices and retrofits to wet or dry-proof a residence were implemented by 15% and 13% of respondents, respectively. Large structural projects, including dams and paved channel systems, were

Table 3. Rank and number of respondents that selected specific mitigation strategies in the *Avoidance* index from 317 respondents.

Rank	Type	n	Percentage
1	Building Codes	152	47.95
2	Watershed Planning	137	43.22
3	Elevation of Structures	125	39.43
4	Impervious Surface Reduction	111	35.20
5	Buyout	85	26.81
6	Buffer	45	14.20

Table 4. Rank and number of respondents that selected specific mitigation strategies in the *Accommodation* index from 317 respondents.

Rank	Type	n	Percentage
1	Onsite Detention	230	72.56
2	Surface Storage	196	61.83
3	New Drainage Systems	183	57.73
T – 4	Bioswales	123	38.80
T – 4	Raingardens	123	38.80
6	Underground Storage	117	36.91
7	Green Roofs	35	11.04

Table 5. Rank and number of respondents that selected specific mitigation strategies in the *Resistance* index from 317 respondents.

Rank	Type	n	Percentage
1	Levees	57	17.98
2	Backup Prevention	47	14.83
3	Home Retrofit	41	12.93
4	Dams Outside Municipality	33	10.41
5	Dams Within Municipality	25	7.89
6	Paved Channels	22	6.94

reportedly used even less frequently. Only local levees or floodwalls to hold back rising waters were practiced by localities with some ubiquity (17%) (Table 5).

6. Discussion

Survey results indicate that urban flooding is a more widespread and impactful phenomenon across the US than previously thought. These findings support recent national reports produced by UMD/TAMUG (2018) and the National Academies of Sciences, Engineering, and Medicine (2019) that reveal urban flooding as a growing source of significant economic loss, social disruption, and housing inequality. While this type of flood impact is more chronic and cumulative than acute storm events, the long-term impacts are more geographically dispersed, affecting a wide range of households, particularly of low and moderate income.

One of the most concerning findings of our survey is amount of flood losses occurring outside of the FEMA 100-year floodplain designation, especially compared to riverine-based flooding more confined to channels. As mentioned above, 83% of respondents reported flood impacts outside of the SFHA (Table S5). Almost all the regulations, planning, and risk communication efforts are targeted within this FEMA-defined boundary. Residents affected by floods outside of the SFHA are often uninsured, unaware of flood risks, and have taken few preventative measures to reduce future impacts. Survey results point to an immediate need to better measure, map, and articulate flood risk in developed areas outside the FEMA 100-year floodplain, especially in low-lying coastal communities.

The multifaceted nature of the urban flood problem in the US requires a variety of mitigation techniques addressing different aspects at different spatial scales. However, the survey finds that the range of flood mitigation strategies implemented locally is very low. Those communities adopting avoidance techniques focus on elevating new structures above base flood elevation (BFE). More ambitious freeboard regulations and programs that provide resources to elevate existing structures will be needed in the future as the extent and depth of flood inundation continues to increase. Planning is also an important avoidance strategy being embraced at the local level, but not as much at the watershed scale, which extends across jurisdictional boundaries and requires collaborative, regional thinking. Accommodation techniques being used by localities are confined to traditional on-site detention techniques often integrated into suburban and commercial development project. This widened approach could include parcel-level detention requirements implemented by residents themselves. Finally, adoption of resistance-based mitigation techniques is surprisingly low considering this is the first approach used in the US for preventing flood loss. We find that resistance strategies, such as dams and levees are considered more of a federal issue. Local decision makers instead focus on more site-specific measures that can are less costly, time-consuming, and politically viable to implement.

A major factor in preventing the wider-scale adoption of mitigation techniques at the local level is not necessarily due to inadequate financial resources or technical acumen, but rather an overall lack of commitment and communication associated with reducing flood risk. For example, while 68% of respondents noted that urban flooding is a significant concern to those affected, only 33% considered it an important issue for elected officials and only 26% for the community at large (Table 6). If urban flooding is going to be genuinely addressed as more than an occasional nuisance, it must rise in importance in the eyes of local elected officials and the larger community responsible for adopting and implementing specific measures. Respondents also noted a lack of risk communication to residents in vulnerable locations. Just over 30% of respondents believed those impacted by urban flooding understand the risk that they face and its potential to become more severe (Table S9). Communicating risk is an important part of raising awareness at the household level that will in turn stimulated decision makers and elected officials to address the problem through mitigation techniques.

7. Conclusions

The results of this study offer a nationally represented glance at the issue of urban flooding, including its extent and impact, the major drivers of the problem, and the degree to which localities are adopting mitigation techniques. While the survey provides an important instrument to diagnose and understand the nature of urban flooding, it should be considered as a first step into this emerging problem. Future research is needed on several fronts. First, more work should be done on the locational characteristics of localized flooding, particularly the role of the built environment in exacerbating or creating adverse impacts. Second, additional study is needed on the specific drivers of

Table 6. Survey responses from 356 respondents to the question: who considers urban flooding to be of significant concern in your community?

Rank	Type	n	Percentage
1	Those Affected	242	67.98
2	Those Responsible for Stormwater Management	217	60.96
3	Elected Officials	120	33.71
4	Not a Significant Problem	99	27.81
5	Community at Large	92	25.84

urban flooding based on different contextual characteristics. The survey is meant only as a descriptive assessment that would inform following-up explanatory work. Third, future research should address the effectiveness of mitigation techniques across the three categories measured in this study. In particular, a better understanding of multiple strategies working synergistically to reduce flood risk and impacts would provide guidance to localities on how to stem future flood losses. Finally, additional work is needed on communicating chronic flood risk to both residents and decision makers, especially how visualizations can help increase awareness and stimulate households to take protective actions.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Hagler Institute for Advanced Study at Texas A&M University, and this paper is based on research supported by the U.S. National Science Foundation PIRE [Grant no. OISE-1545837]. The findings and opinions reported are those of the authors and are not necessarily endorsed by the funding organizations or those who provided assistance with various aspects of the study.

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References

Aulenbach, B. T., M. N. Landers, J. W. Musser, and J. A. Painter. 2017. "Effects of Impervious Area and BMP Implementation and Design on Storm Runoff and Water Quality in Eight Small Watersheds." *JAWRA Journal of the American Water Resources Association* 53 (2): 382–399. doi:10.1111/1752-1688.12501.

Beatley, T. 2009. *Planning for Coastal Resilience: Best Practices for Calamitous Times*. Washington, DC: Island Press.

Bertilsson, L., K. Wiklund, I. M. Tebaldi, O. M. Rezende, A. P. Verol, and M. G. Miguez. 2019. "Urban Flood Resilience – A Multi-criteria Index to Integrate Flood Resilience into Urban Planning." *Journal of Hydrology* 573: 970–982. doi:10.1016/j.jhydrol.2018.06.052.

Birkland, T. A., R. J. Burby,D. Conrad,H. Cortner,and W. K. Michener. 2003. "River Ecology and Flood Hazard Mitigation." *Natural Hazards Review* 4 (1): 46–54. doi:10.1061/(ASCE)1527-6988(2003)4:1(46).

Blessing, R., A. Sebastian, and S. D. Brody. 2017. "Flood Risk Delineation in the U.S.: How Much Loss are We Capturing?" *Natural Hazards Review* 18 (3): 04017002. doi:10.1061/NH.1527-6996.0000242.

Brody, S. D., and K. Atoba. 2017. "Flood Resiliency in the United States: Setting a Framework for Reducing Losses." In *Vulnerability and Resilience to Natural Hazards*, edited by S. Fuchs and T. Thayler, 237–256. UK: Cambridge University Press.

Brody, S. D., W. E. Highfield, and J. E. Kang. 2011. *Rising Waters: Causes and Consequences of Flooding in the United States*. Cambridge, UK: Cambridge University Press.

Brody, S. D., W. E. Highfield, and R. Blessing. 2015. "An Empirical Analysis of the Effects of Land Use/Land Cover on Flood Losses along the Gulf of Mexico Coast from 1999 to 2009." *Journal of the American Water Resources Association (JAWRA)* 51 (6): 1556–1567. doi:10.1111/1752-1688.12331.

Brody, S. D., W. E. Highfield, R. Blessing, T. Makino, and C. Shepard. 2017. "Evaluating the Effects of Open Space Configurations in Reducing Flood Damage along the Gulf of Mexico Coast." *Landscape and Urban Planning* 167: 225–231. doi:10.1016/j.landurbplan.2017.07.003.

Chavez, N., and M. Krupa. 2017. "New Orleans Flooding and Pumping System Crisis By the Numbers." *CNN*, August 12. http://www.cnn.com/2017/08/11/us/new-orleans-flooding-by-the-numbers/index.html

CNT (Center for Neighborhood Technology). 2014. "The prevalence and cost of urban flooding: A case study of Cook County, IL." https://www.cnt.org/publications/the-prevalence-and-cost-of-urban-flooding

Craig, T. 2017. "It Wasn't Even a Hurricane, But Heavy Rains Flooded New Orleans as Pumps Faltered." *The Washington Post*, August 9. https://www.washingtonpost.com/national/it-wasnt-even-a-hurricane-but-heavy-rains-flooded-new-orleans-as-pumps-faltered/2017/08/09/b3b7506

GCRT (Governor's Commission to Rebuild Texas). 2018. *Eye of the Storm*. College Station, TX: Texas A&M University System.

Gori, A., R. Blessing, A. Juan, S. D. Brody, and P. Bedient. 2019. "Characterizing Urbanization Impacts on Floodplain through Integrated Land Use, Hydrologic, and Hydraulic Modeling." *Journal of Hydrology* 568: 82–95. doi:10.1016/j.jhydrol.2018.10.053.

Graf, W. L. 2001. "Dam Age Control: Restoring the Physical Integrity of America's Rivers." *Annals of the Association of American Geographers* 91 (1): 1–27. doi:10.1111/0004-5608.00231.

Highfield, W. E., S. Norman, and S. D. Brody. 2012. "Examining the 100-Year Floodplain as a Metric of Risk, Loss, and Household Adjustment." *Risk Analysis* 33 (2): 186–191. doi:10.1111/j.1539-6924.2012.01840.x.

Highfield, W. E., and S. D. Brody. 2013. "Evaluating the Effectiveness of Local Mitigation Activities in Reducing Flood Losses." *Natural Hazards Review* 14 (4): 229–236. doi:10.1061/(ASCE)NH.1527-6996.0000114.

Jiang, Y., C. Zevenbergen, and Y. Ma. 2018. ""Urban Pluvial Flooding and Stormwater Management: A Contemporary Review of China's Challenges and "Sponge Cities" Strategy." *Environmental Science & Policy* 80: 132–143. doi:10.1016/j.envsci.2017.11.016.

Lewis, S. D. 2017. "Detroit Launches Program to Reduce Street Flooding." *The Detroit News*, August 22. https://www.detroitnews.com/story/news/local/detroit-city/2017/08/22/detroit-street-flooding/104853126/

Mahmood, M. I., N. A. Elagib, F. Horn, and S. A. G. Saad. 2017. "Lessons Learned from Khartoum Flash Flood Impacts: An Integrated Assessment." *Science of the Total Environment* 601 (1): 1031–1045. doi:10.1016/j.scitotenv.2017.05.260.

Melillo, J. M., R. Terese, and F. W. Yohe. 2014. "Climate Change Impacts in the United States: The Third National Climate Assessment." *U.S. Global Change Research Program*, 841.

Mogollón, B., E. A. Frimpong, A. B. Hoegh, and P. L. Angermeier. 2016. "Recent Changes in Stream Flashiness and Flooding, and Effects of Flood Management in North Carolina and Virginia." *JAWRA Journal of the American Water Resources Association* 52 (3): 561–577. doi:10.1111/1752-1688.12408.

National Academies of Sciences, Engineering, and Medicine. 2019. *Framing the Challenge of Urban Flooding in the United States*. Washington, DC: National Academies Press.

Nilson, C., and K. Berggren. 2000. "Alterations of Riparian Ecosystems Caused by River Regulation." *BioScience* 50 (9): 783–792. doi:10.1641/0006-3568(2000)050[0783:AORECB]2.0.CO;2.

Nowak, D. J., and J. T. Walton. 2005. "Projected Urban Growth (2000–2050) and Its Estimated Impact on the US Forest Resource." *Journal of Forestry* 103 (8): 383–389.

State of Illinois, Department of Natural Resources. 2015. "Report for the Urban Flooding Awareness Act." June. http://www.dnr.Illinois.gov/waterresources/documents/final_ufaa_report.pdf

UMD (University of Maryland), Center for Disaster Resilience, and Texas A&M University, Galveston Campus (TAMUG), and Center for Texas Beaches and Shores. 2018. *The Growing Threat of Urban Flooding: A National Challenge*. College Park: A. James Clark School of Engineering.

Winters, B. A., J. Angel, J. Byard, A. Flegel, D. Gambill, E. Jenkins, S. McConkey, M. Markus, B. Bender, and M. O'Toole. 2015. *Report for the Urban Flooding Awareness Act*. Illinois: Illinois Department of Natural Resources.

Zhour, Q. G., L. J. Su, and Y. Ren. 2019. "Comparison of Urbanization and Climate Change Impacts of Urban Flood Volumes: Importance of Urban Planning and Drainage Adaptation." *Science of the Total Environment* 658 (25): 24–33. doi:10.1016/j.scitotenv.2018.12.184.