ISSUE BRIEF

August 2021

Wharton
University of Pennsylvania
Risk Management and Decision Processes Center

The Coming Storm: How U.S. Cities Are Managing Stormwater from Increasingly Extreme Rainfall Events

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In the United States, extreme rainfall events are becoming more frequent and more intense as a result of climate change. From 1958 to 2016, the total amount of annual precipitation falling during the heaviest 1% of events increased in the continental United States and Alaska, with the largest increases occurring in the Northeast (55%) and Midwest (42%) (USGCRP 2018). These trends are expected to continue as the planet warms (Prein et al. 2017). At the same time, some cities are experiencing an increase in urbanization, which increases impervious surface areas, and an influx of residents, which exposes more people to damages (Swain et al. 2020).

Urban stormwater refers to runoff in cities following heavy rainfall events. Stormwater flows over the ground into channels and built conveyance systems (such as pipes and ditches), ultimately reaching a stream, river, or other water body. While some stormwater infiltrates into the ground, water retention is lower in urban areas because the soil is compacted, which reduces its ability to absorb stormwater, and also due to reduced evapotranspiration from less vegetation (National Research Council 2009). Impervious surface areas, such as roads and buildings, are a barrier for stormwater infiltration that aggregate and often accelerate the conveyance of stormwater.

Historically, stormwater runoff in urban environments has been managed through pipe systems or natural drainageways that ultimately discharge into water bodies or, in the case of combined sewer and stormwater systems, convey wastewater to a centralized treatment facility. Combined systems discharge untreated wastewater into water bodies when overwhelmed—referred to as combined sewer overflows—which occur when runoff exceeds the system's design capacity. Some cities have separated systems that collect and convey wastewater

KEY FINDINGS

- Climate change is increasing the frequency and intensity of extreme rainfall events in many U.S. cities, driving up the risk of localized stormwater flooding.
- Stormwater has historically been managed only for water quality, since it can wash pollutants into waterbodies. Cities are now having to also manage stormwater for high volumes of water that flood streets and buildings and overwhelm stormwater systems.
- There is a regulatory gap in federal policies, technical support, and guidance since no single agency is focused on stormwater flooding.
- Cities will need to invest substantially in new stormwater infrastructure. Historically, these costs have fallen on ratepayers, which could put financial pressure on residents that are already cost burdened.
- As extreme rainfall continues to worsen, cities will need to combine infrastructure investments with additional supporting policies, including risk communication, improved planning, emergency response frameworks, and attention to flood insurance for residents and businesses.

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and stormwater separately. Extreme events can also cause overflows from separated sewer systems onto streets and sewer backups into homes.

Since stormwater discharges can carry a host of pollutants, stormwater management has largely developed in response to regulations under the Clean Water Act to improve water quality (Cousins and Hill 2021). While trends in increasing rainfall are raising concerns about the impact of additional stormwater runoff on water quality—such as increases in overflows from sewer systems—it is also increasing rainfall-related flooding in cities around the country.

This Issue Brief looks specifically at stormwater flooding (also called pluvial flooding) and how U.S. cities can manage increases in water volume, and not just water quality. In the next section, we discuss the data, modeling, institutional, and financial challenges facing cities, and how they are responding to these challenges. We then detail additional supportive policies that are needed, such as regulations and planning, communication and outreach, emergency response programs, and increased uptake of flood insurance—that can help residents and businesses at risk from extreme rainfall events. We conclude with policy recommendations.

CITIES RESPOND

As extreme rainfall events worsen, there is a need nationwide to replace or update existing stormwater infrastructure that was typically designed for less heavy rainfall (American Society of Civil Engineers 2021). Capital investment needs are estimated at $271 billion over a 20-year period (Reidmiller et al. 2018). Recognizing that further expanding gray infrastructure is often cost-prohibitive, many cities are embracing decentralized approaches that mimic or restore natural systems, an approach that is supported by the EPA as a way to meet regulatory requirements regarding water quality (U.S. EPA 2007; 2015).[2] This "green stormwater infrastructure" (GSI) approach is often more cost-effective than traditional approaches (Braden and Ando 2011) while also providing a range of co-benefits (Ando and Netusil 2018). GSI has primarily been designed to manage peak flows, reduce runoff volumes, and improve water quality from less intense rainfall events, but a growing number of cities are starting to use green approaches to manage extreme rainfall as well. This requires adopting design guidelines that can accommodate larger storms, greater infiltration volumes, and creating a network of interventions (McPhillips et al. 2020).

Stormwater and urban flooding are primarily managed at the local level. Local agencies have deep knowledge of their stormwater infrastructure, climatic conditions, state and local regulations, and the local built environment. While some cities are demonstrating leadership to address the growing risk of stormwater flooding, there is a need for scientific, institutional, and financial support for them to adequately address this risk, given the lack of a technical consensus on best practices (Fischbach et al. 2020). We briefly review these needs in the following sections.

Data and Modeling Challenges

While global scale climate models are being down-scaled to the regional level, their temporal and spatial resolutions are often still too aggregated to provide detailed guidance for stormwater flooding. Pluvial flood risk is also difficult to model, since it depends on fine-scaled data and localized conditions, such as whether storm drains are cleared of debris. Some cities may not have the needed data or the resources to invest in sophisticated modeling to account for integrated, urban systems (Fischbach et al. 2020).

Additionally, there is a lack of accurate damage estimates from pluvial flooding, including data and metrics that can be used to estimate the distributional impacts of floods (Hino and Nance 2021; Rosenzweig et al. 2018; University of Maryland 2018). Some of this data is beginning to be collected. Philadelphia, for example, is surveying residents about flooding to inform their policy responses. Also lacking are agreed-upon co-benefit estimates for GSI (Zuniga-Teran et al. 2020), so these have not typically been incorporated into stormwater management manuals that guide utility investments (McPhillips et al. 2020). This means that utilities base decisions on cost-effectiveness, instead of including the full range of benefits, which may ultimately lead to suboptimal outcomes (Ando and Netusil 2018). Research is underway to fill these

[2] Section 502 of the Clean Water Act defines green infrastructure as "...the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters."

gaps and develop tools to help inform best practices (Raymond et al. 2017), but further studies driven by local needs are required.

Institutional Challenges

Currently, there is a regulatory gap in federal policies, regulations, technical support, and guidance about pluvial flood risk (Fischbach et al. 2020), as no single agency is focused on stormwater flooding. The EPA regulates water quality through the Clean Water Act (CWA), but does not address flood concerns.[3] The Federal Emergency Management Agency (FEMA) and the U.S. Army Corps of Engineers address multiple aspects of flood risk, but limit their attention almost exclusively to riverine and coastal flooding.

Some cities and NGOs are creating groups to share best practices about pluvial flooding (Fischbach et al. 2020; Rosenzweig et al. 2019), but this cannot overcome the lack of federal guidance and support. Barriers also exist within local agencies (Dhakal and Chevalier 2017), including the use of design manuals for infrastructure investments that are based on historic rainfall patterns and are typically designed for 2- to 10-year rainfall events (Rosenzweig et al. 2018). There also exist uncertainties about the effectiveness of GSI, especially for extreme rainfall events (Rosenzweig et al. 2018; NRC 2009); concerns and uncertainty about maintenance needs and costs, which are often higher than traditional gray infrastructure (Taguchi et al. 2020; Pour et al. 2020); uncertainty about whether the public will accept these new approaches (Everett et al. 2018; Zuniga-Teran et al. 2020); and a resistance to these approaches by some agency staff (Dhakal and Chevalier 2017; Shandas et al. 2020).

Financial Challenges

The needed new investments in stormwater management will be expensive, with costs primarily borne by ratepayers due to limited state and federal funding (Cousins and Hill 2021). Federal funding for water and wastewater utility infrastructure decreased more than four-fold between 1980 and 2017 with funding shifting from grants to subsidized loans (CBO 2018; Eskaf 2015). In 2017, state and local spending accounted for 96% of total public spending with operation and maintenance costs reaching a peak of over 72% of total public spending (CBO 2018).

Many cities pay for capital investments and operations through stormwater fees. These fees are typically calculated using the average impervious surface area of residential properties (Cousins and Hill 2021), which implicitly subsidizes properties with a large amount of impervious surface area and may be regressive.[4] EPA considers drinking and wastewater fees to be a “high burden” if they exceed 2% of median household income (Throwe et al. 2020). Recently, scholars have called for a more sophisticated treatment of affordability, which would help inform policy responses (Raucher 2019). Some cities are taking steps to address affordability challenges through customer assistance programs. In 2017, Philadelphia adopted the first income-based billing program for water services (Mack et al. 2020). Federal grants could also help address the regressively of current funding sources by lessening the burden on lower-income ratepayers.

There has been experimentation with innovative financing arrangements, such as green bonds and impact bonds, but these simply spread costs over time and still need an ultimate funding source. The extent to which these bonds save money for the local government appears related to independent certification as to the "greenness" of the bond (Hyun et al. 2020). Still, some cities have found them a useful vehicle and they could be harnessed for needed upgrades. In 2014, Washington, DC pioneered the use of an environmental impact bond to pay for GSI investments designed to reduce combined sewer overflows.[5] Other cities, such as Chicago, San Francisco, and Columbia, South Carolina, have also used green bonds for stormwater investments.

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[3] In 2019, Section 402(s) was added to the CWA. This provides utilities with more flexibility to meet human health and water quality objectives, but it is unclear whether non-CWA factors, such as flooding and climate change, can be included when prioritizing capital investments (Fischbach et al. 2020).

[4] Another approach is to more closely align fees with a property’s stormwater runoff; for example, Portland, Oregon, has a program that reduces stormwater bills for property owners who manage more of their roof and pavement runoff on their property by disconnecting downspouts so they drain to lawns, rain gardens, or drywells. The program also provides a discount for property owners who have planted trees, installed green roofs, or have less than a threshold amount of impervious surface area. See: https://www.portlandoregon.gov/bes/41976

[5] See multiple reports on this bond from DC Water at: https://www.dcwater.com/green-bonds.

ADDITIONAL SUPPORTIVE POLICIES

As rainfall-related flood risks escalate, cities have recognized they must move beyond a limited focus on the infrastructure of moving the water to adopt an array of supporting policies. Many of these depend upon better understanding where the risks of pluvial flooding are greatest. These areas are not captured on FEMA flood maps and so cities are having to invest in developing their own assessments, sometime by harnessing citizen input about where they have observed or experienced flooding.

Regulations and Planning

As cities experience an increase in extreme rainfall, some are creating new plans, updating building codes, and adopting regulations to reduce impervious cover, keep more water on-site, and maintain beneficial drainage patterns. These include regulations that preserve wetlands, limit erosion in construction, or require installation of aquatic buffers; increased standards regarding the amount of stormwater that must be managed onsite by new or redeveloped properties; and incorporation of higher stormwater standards for transportation planning and zoning. An increasing number of cities have climate adaptation plans and these should address pluvial flood concerns (Bierbaum et al. 2013). New York City has gone a step further, creating a standalone stormwater plan that explicitly addresses management of the increased risk of rainfall flooding (NYC Mayor's Office of Resiliency 2021).

Changes in regulations and planning also extend to infrastructure. Kim et al. (2017) discuss the need for a paradigm shift from "fail-safe" to "safe-to-fail" infrastructure design and planning that seeks to minimize the impact of infrastructure failures. For example, roadways, walkways, and plazas can be designed to be inundated during extreme rainfall events with some infrastructure designed to store excess stormwater (Matos Silva and Costa 2016).

Communication and Outreach

Flood risk communication is dominated by the National Flood Insurance Program (NFIP), which has mapped the 1% annual chance (100-year) floodplain in communities around the country. Unfortunately, NFIP maps have typically focused exclusively on riverine and coastal flood risk and not adequately mapped pluvial risk. As such, many homeowners are not informed when they are at heightened risk of pluvial flooding from extreme rainfall. This can lead households to fail to undertake actions that could reduce possible damage, such as changing grading around their home, installing sump pumps and/or backwater preventers, fixing problems with gutters or downspouts, or using flood resistant materials.

To help improve this situation, some cities are investing more in their own local outreach about pluvial flooding. For example, as part of their Climate Vulnerability Assessment, the Twin Cities in Minnesota created what they call a Localized Flood Map Screening Tool, which maps areas at risk of flooding from extreme rainfall—areas they call Bluespots.[6] The tool lets users focus in on particular properties and gives estimates of possible flood depths. As another example, New York City has a stated objective to inform the public about flooding from extreme rainfall. In addition to their recently released first stormwater resiliency plan, they produced public maps of different rainfall scenarios.[7] The city has also created a homeowners guide to "rain event preparedness."[8] This guide offers suggestions of actions homeowners can take to lower their flood risk, such as installing backwater valves, reducing impervious cover, and protecting areas below street level.

Flood Insurance

Floods are not covered by standard homeowners policies but require purchase of a separate flood policy from either a private insurer or the NFIP. Those with federally-backed mortgages in FEMA mapped 100-year floodplains are required to have flood insurance, but since NFIP maps do not typically include rainfall-related flood risk, many who are at risk are

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[6] See maps online here: https://gisdata.mn.gov/dataset/us-mn-state-metc-env-local-flood-screening.
[7] See maps online here: https://experience.arcgis.com/experience/4b290961cac34643a49b9002f165fad8/.
[8] Guide online at: https://www1.nyc.gov/assets/dep/downloads/pdf/climate-resiliency/flood-preparedness-flyer.pdf.

left uninsured—even though an NFIP policy would pay for damage from stormwater flooding.[9] When pluvial risk is included, millions more households are shown to be at risk of flooding than FEMA maps indicate (Wing et al. 2018). Businesses, too, require flood insurance for recovery, but research has found smaller and younger firms are less likely to have flood coverage (Collier et al. 2019).

Without flood insurance, there are few other sources of financial support. This is because rainfall-related flood events tend to be localized and thus do not rise to the level of severity that would trigger a federal disaster declaration; as such, federal disaster grants and loans are not often available after pluvial flooding.

Several cities are increasing their promotion of flood insurance in areas that flood from heavy rain. FEMA, too, has been using a slogan: "Where it can rain, it can flood," to help educate people about the need for flood insurance in places at risk of rainfall flooding. Some cities are seeing that once residents experience a couple of rainfall related flood events, the purchase of flood insurance increases.[10]

While some areas at risk for pluvial flooding may have less expensive flood insurance than properties subject to coastal storm surge or riverine flooding, the cost could still be prohibitive for low-income households (Netusil et al. 2021). FEMA and the National Academy of Sciences have suggested that the U.S. Congress adopt a means-tested assistance program to assist these households (NRC, 2015; FEMA 2018). In the absence of such a policy, some local governments, like Portland, Oregon, have pursued their own innovative approaches to help lower-income residents with the cost of flood insurance (Sherman and Kousky 2018).

Emergency Response

Rainfall-related flash flood events can require a swift emergency response, involving coordination across agencies to deal with flooded roadways and transit systems, residents in distress, and localized property damage. Several local governments have developed or updated emergency response plans to deal with intense rainfall flooding, identified critical infrastructure at risk and mitigation measures for these structures, and also worked with neighboring jurisdictions to collaborate on a response (Rosenzweig et al. 2019). For example, after a severe rainfall flood event in New York City in 2007, the city developed a Flash Flood Emergency Response plan, coordinating activities across at least eight different agencies, including Emergency Management and the Departments of Transportation, Sanitation, and Environmental Protection, as well as the Fire and Police Departments (NYC 2021). Pre-storm actions, such as cleaning inlets and storm drains, can reduce the ultimate impacts, but also requires a coordinated program in the city to track storm forecasts and respond.

CONCLUSIONS AND POLICY RECOMMENDATIONS

Extreme rainfall events are impacting cities throughout the United States, yet, a holistic approach to stormwater management that includes local, state, tribal, and federal governments is lacking. Cities need an integrated planning framework to manage for the multiple impacts of stormwater runoff, recognize the cross-boundary nature of extreme rainfall events, and plan for the possibility of compound extreme events.

Extreme rainfall will worsen as the planet warms and substantial investments in stormwater infrastructure will be needed, creating an opportunity for cities to not only improve resilience, but to also address a legacy of past actions that disproportionately exposed certain residents to the impacts of stormwater runoff and urban flooding. Cities will also need to combine infrastructure investments with additional supporting policies, such as risk communication, improved planning, emergency response frameworks, and attention to flood insurance for residents and businesses to help them prepare for "the coming storm."

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[9] The NFIP defines a flood as a "general and temporary condition of partial or complete inundation of two or more acres of normally dry land area or of two or more properties (at least one of which is your property)" that occurs from "overflow of inland or tidal waters," "unusual and rapid accumulation or runoff of surface waters from any source," mudflows, or subsidence along a water body caused by waves or currents.

[10] The authors were told this in personal communication with a couple city officials. Academic research has found that disasters temporarily increase purchase of flood insurance. See, for example, Kousky (2017).

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