Policy brief

Stormwater management

Urban flooding is intensified by outdated design guidelines and lack of a systems approach

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Intro

Despite substantial investments in urban stormwater management systems around the world, cities are experiencing soaring impacts that are inconsistent with assumed levels of flood protection. This suggests flaws in existing stormwater design methods and guidelines that currently do not properly account for the complexity of flood flows in urban landscapes and their interactions with infrastructure and with natural and artificial water bodies.

Messages for policy

- Holistic, system-wide approaches to flood mitigation should be promoted, in contrast to the current practice of localized solutions.
- Stormwater design guidelines require revisions that account for the connectivity among all system elements, including subsurface infrastructure, open channels, and natural and built surfaces.
- Advanced hydrologic and hydrodynamic models that can represent the full spectrum of urban stormwater system elements should be mandated for more accurate flood risk assessment.
- Design scenarios should be diversified to account for complex rainfall patterns and other factors controlling flood flows in urbanscapes, enabling more comprehensive evaluation of flooding variability.
- Flood hazard mapping systems, such as FEMA's FIRM floodplain maps in the U.S., require updates to accurately represent the extent and severity of potential flooding.

The policy problem

Design guidelines and best practices for urban stormwater drainage infrastructure aim to ensure a certain level of protection against floods. In practice, however, these systems do not always meet their assumed performance expectations, and policymakers face uncertainty about causes. This also raises doubts about the efficacy of future investments aiming to enhance cities' flood resilience. Current guidelines focus on understanding the performance of specific infrastructure elements – such as storm drains, culverts, and pipelines – in isolation, rather than as part of a broader urban landscape. Specifically, current guidelines fail to account for the complexity of flood 'connectivity' in urban areas – how flood flows can interact in subterranean pipelines, open channels, and over natural and human-made surfaces. Despite substantial progress, models used for stormwater design remain too simplistic and are unable to fully incorporate such interactions. Thus, design scenarios overlook connected system elements and neglect the potential for flooding from sources outside of a localized area.

The findings

We find that human-engineered infrastructure can introduce additional stormwater flow connectivity in urban environments that may be crucial for flood risk (Fig. 1). Specifically, inundation can be exacerbated in areas where river channels are connected to subterranean infrastructure. We find this has immediate implications for stormwater design, as differing assumptions about flood connectivity between river flooding and infrastructure can yield drastically different estimates of potential inundation. The ubiquitous practice of ignoring this connectivity–assessing the performance of infrastructure elements in isolation and with overly simplistic rainfall scenarios – can lead to substantial errors, resulting in reduced infrastructure effectiveness. Paradoxically, design errors can reverse stormwater network functionality in the real world, leading to flooding even in the absence of local rainfall. While this study illuminates broader challenges in stormwater network design and flood risk management, solutions will need to be tailored to the needs and unique characteristics of individual communities.

The study

The historic 2014 storm resulted in severe flooding in Southeast Michigan, USA. The study focuses on an $8.8\ km^2$ area in Warren city, which features a complex network of diverse drainage elements including culverts, underground stormwater drains, and outfalls; the latter provide hydraulic connection to open river channels. To accurately model flood events, the researchers gathered high-resolution data and conducted field surveys to validate these data. The study used an advanced, high-fidelity hydrodynamic model to simulate flooding scenarios, comparing different configurations of stormwater infrastructure. Key experiments included simulations with and without local rainfall, as well as comparisons between "Integrated" outfalls (allowing flow reversals) and "Controlled" outfalls (assuming unrestricted discharge of stormwater into river channels). These simulations explore how flood connectivity is augmented by human-engineered infrastructure to influence flood severity in urban environments, and its implications for current and future stormwater design practices.

Further Reading

Rentschler, J. *et al.* Global evidence of rapid urban growth in flood zones since 1985. *Nature* **622**, 87-92, doi:10.1038/s41586-023-06468-9 (2023). This study demonstrates that numerous major cities worldwide have experienced an increase in both the frequency and severity of flood events.

Qiao, X.-J., Kristoffersson, A. & Randrup, T. B. Challenges to implementing urban sustainable stormwater management from a governance perspective: A literature review. *Journal of Cleaner Production* **196**, 943-952, This study highlights the various difficulties encountered in establishing efficient stormwater systems.

Rosenzweig, B. R. *et al.* The Value of Urban Flood Modeling. *Earth's Future* **9**, doi:10.1029/2020ef001739 (2021). Their study presents mathematical urban flood models as critical tools for flood risk assessment, emergency operations, and resilience planning in cities.

Thorndahl, S., et al., Weather radar rainfall data in urban hydrology, *Hydrol. Earth Syst. Sci.,* 21, 1359–1380, https://doi.org/10.5194/hess-21-1359-2017 (2017). This study reviews progress in rainfall estimation using radar for urban hydrology and flooding.

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Ethics declarations

Competing interests

The authors declare no competing interests.

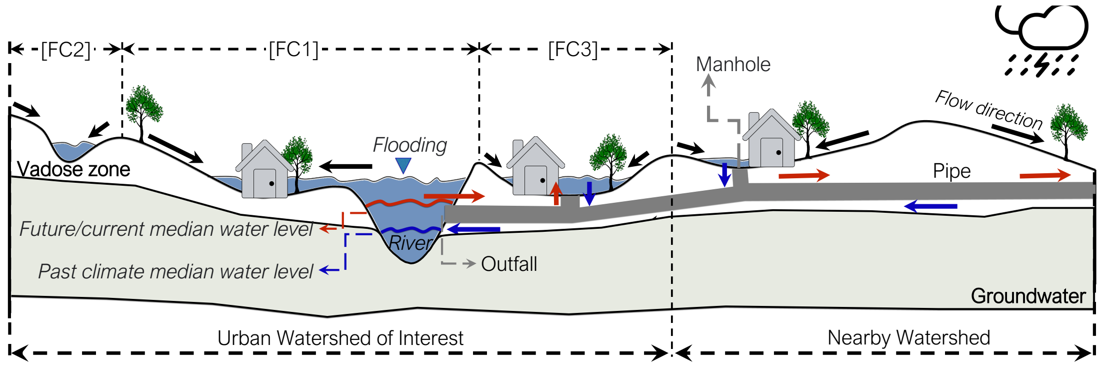

Figure 1. Schematic of key urban flood concepts (FCs). FC1 (river-induced flooding), FC2 (rainfall-induced flooding), and FC3 (infrastructure-induced flooding). The diagram shows residential and non-residential areas, underground stormwater infrastructure, and river channels. Arrows indicate various flow directions, including potential flow reversals. Blue and red curved lines represent non-flooding and flooding river levels, respectively. Figure adapted under a Creative Commons license CC BY 4.0.