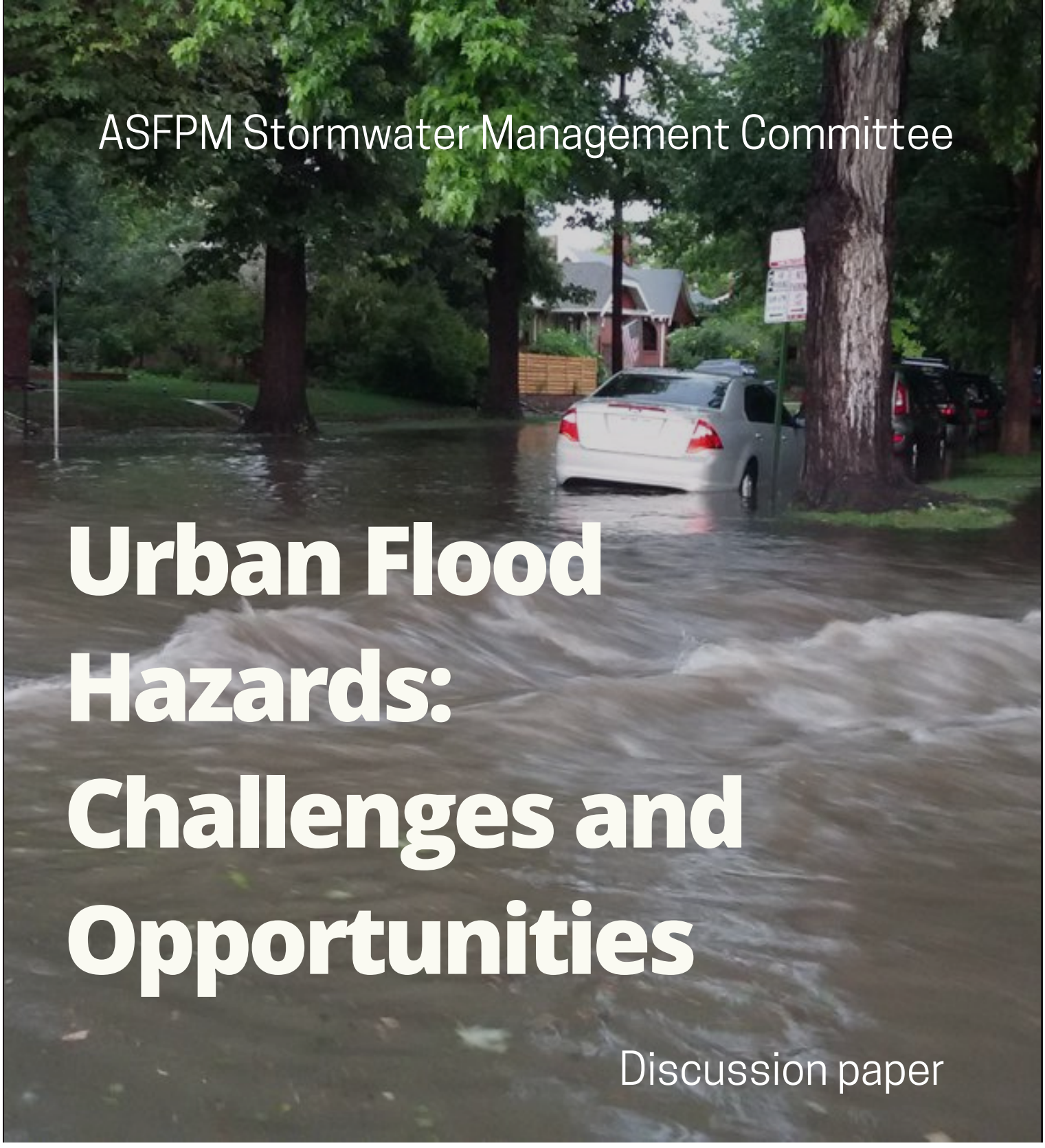

ASFPM Stormwater Management Committee

Urban Flood Hazards: Challenges and Opportunities

Discussion paper

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Discussion Paper

Urban Flood Hazards: Challenges and Opportunities

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INTRODUCTION:

Urban flooding is a multi-faceted hazard and has numerous causes. As defined in the recently published summary report of the 2019 Gilbert F. White National Flood Policy Forum published by the Association of State Floodplain Managers (ASFPM) Foundation, Urban Flooding, Moving Towards Resilience, urban flooding is defined as "flooding that occurs in a densely populated area. Whatever the specific cause(s) of inundation—cloudburst, hurricane, groundwater seepage, river overflow, infrastructure failure—stormwater systems are overwhelmed, and water accumulates in the paved-over, built up urban environment with nowhere to go." The impacts of urban flooding, both financial and social, pose significant challenges to local government leaders, managers, and the citizens who reside in these at-risk communities.

This discussion paper, developed by ASFPM's Stormwater Management Committee, focuses on one specific area of urban flooding, mainly areas outside of riverine and coastal flooding zones that are inundated due to surface runoff, i.e. areas where excess stormwater runoff exceeds the conveyance capacity of pipe and roadway systems, resulting in flooding that inundates structures and prevents safe access for emergency vehicles and personnel. Specifically, this paper seeks to provide a discussion of the associated challenges of urban flooding, concepts related to planning and mitigation to reduce future flood losses, and recommendations at the local and national scale to address urban flooding in communities nationwide. This paper provides background and discussion, however it does not represent a position or policy of the ASFPM, a non-profit organization dedicated to the No Adverse Impact approach to reducing flood losses and protecting floodplain functions and resources in the United States.

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URBAN FLOODING: THE UNIDENTIFIED HAZARD

Flood Hazard Identification Under the NFIP: Riverine and Coastal Mapping

Congress established the National Flood Insurance Program (NFIP) in 1968 with the passage of the National Flood Insurance Act, now codified in 44 CFR, to partner with local governments and enable owners of real property in participating communities to purchase federally administered flood insurance.

In 1979, the Flood Insurance Administration (FIA) and the NFIP were moved under the authority of the Federal Emergency Management Agency (FEMA). Since the creation of the NFIP, the program has actively mapped flood hazards throughout the United States to assess flood risk and establish insurance rates. These mapping efforts have primarily focused on threats from rivers and coastal storm surge. Between 2003 and 2008, FEMA digitized legacy flood hazard mapping and completed new flood insurance studies (FIS) through Flood Map Modernization (Map Mod). In 2009, FEMA began using Risk Mapping, Assessment, and Planning (Risk MAP) to update flood risk identification. To date, FEMA has mapped and established Special Flood Hazard Areas (SFHAs) for over 90% of the major population areas within the United States, identifying flood risk for both coastal and riverine environments.

Although an ambitious program that has made significant progress in identifying flood hazards nationwide, flood losses outside of the FEMA mapped 100-year floodplain continue to represent a significant portion of claims made by policyholders throughout the United States; approximately 25% of all NFIP claims annually. This statistic indicates that the floodplain mapping completed to date may not be accurate, may not be representative of actual conditions, or may be overlooking additional flood hazards that have not been previously mapped. Local floodplain and stormwater managers in highly urbanized areas understand that there are additional, unidentified flood hazards caused by excess urban stormwater runoff that lie beyond the boundaries of the currently established SFHAs mapped along rivers and coastal areas. The flood managers, tasked with reducing flood losses and communicating flood risk to citizens to maximize insurance purchases, are faced with developing strategies to address not only their traditional riverine and coastal flood risk, but also the risks and challenges associated with urban flooding.

Flood Hazard Identification: The Urban Flooding Problem

As cities grew over the last two centuries, many natural floodplains were channelized and filled in to accommodate population growth and community development. To those planning and developing these metropolitan areas, local drainageways may have appeared to be very small, posing relatively minor flood risks; the existing floodplains and their natural and beneficial stormwater management functions were often not a major consideration in the development and growth of these conurbations. To mitigate flood risk, stormwater pipe systems were built to compensate for the loss in conveyance that occurred due to the filling and encroachment of historic drainageways within the floodplain. Additionally, until the late twentieth century, increased runoff from new impervious areas upstream of these stormwater systems was not mitigated or controlled. Unfortunately, local stormwater systems in many developed watersheds are undersized, only providing runoff conveyance for events with frequencies ranging from one to 10 years (100% - 10% annual chance events). Many of these existing systems are not well

maintained, resulting in significant reductions in their original capacity. When larger, less frequent events occur, storm conveyance systems are overwhelmed, and the residual runoff remains on the ground, resulting in flooding that inundates streets and existing structures. Note that although streets are typically included as part of the stormwater conveyance system, the types of inundation referred to here are in excess of local storm drainage criteria, often resulting in completely impassable streets and intersections and most likely resulting in flood damage to existing structures. This is especially common in historic areas where infrastructure was not designed to meet current local drainage criteria. In addition to these existing systems being undersized, there has been an increase in the frequency and intensity of rainfall events, an indicator of climate change, resulting in more frequent and persistent flooding of the built environment. Many local stormwater and floodplain administrators are aware of urban flooding issues in their communities because of regular complaints, photos, videos, and repetitive flood losses in unmapped areas. However, these hazards often remain unmapped and unregulated due to a variety of reasons, including limited funding or political will.

Over the past decade, local government agencies and floodplain management professionals have taken a strong interest in identifying, mapping, managing, and mitigating urban flood hazards and, ultimately, reducing flood losses in unmapped areas. Where these flood-prone urban areas have been identified, strategies to address localized flooding typically come with very high capital improvement costs or feasibility challenges that are increasingly difficult to overcome.

This discussion paper:

- Provides an overview of the challenges associated with urban flood hazards
- Offers a framework to assess, identify, plan, mitigate, and manage urban flood hazard areas to reduce future flood losses
- Suggests recommendations on the local and national scales to assist communities with identifying and mitigating urban flood hazards

This discussion paper is specifically meant for local stormwater and floodplain managers, but also serves as a reference for all engineering and planning professionals within the floodplain and stormwater community.

SECTION 2: BACKGROUND

PRIMARY CAUSES OF URBAN FLOODING

Many communities have developed local drainage and stormwater criteria to address increased runoff due to development, and to reduce flooding of existing structures using runoff conveyance systems. However, cities throughout the country continue to sustain flood damage; in fact, flood damage to structures outside of the SFHA has been steadily increasing. The primary causes of flooding in these urban areas include the historic loss of natural drainageways; historic development, land use, and stormwater management criteria; inadequate stormwater management criteria; increased impervious surfaces (development) upstream of existing stormwater conveyance systems; levee systems and residual local flooding; combined sewer systems and sewer backups; insufficient maintenance; and climate change.

Historic Loss of Natural Drainageways: Before development, a significant portion of rainfall was infiltrated, and the remaining stormwater runoff was conveyed in swales, gulches, gullies, low-lying drainageways, washes, creeks, rivers, and streams. Smaller natural drainageways were often filled or replaced by storm drainage systems that were only built to convey small, frequent rainfall events. The loss of natural drainageways also included the loss of effective and efficient flowpaths. In many urbanized areas, water can no longer follow the topography of the land, instead meandering through flood-prone areas (sometimes against grade) making make its way downhill. This dramatically increases flood potential.

Figure 1. Construction of a brick storm drain system used to replace surface conveyance in a natural swale in the City and County of Denver, circa 1920 (Denver Public Library).

Historic Development, Land Use, and Stormwater Management Criteria: Historic development occurred with minimal or no criteria for stormwater mitigation, resulting in non-existent or undersized stormwater drainage systems. In the absence of drainage criteria, excess stormwater runoff due to

increases in impervious surfaces was not controlled using infrastructure such as detention or retention facilities. The excess runoff from development overwhelmed downstream drainageways or pipe systems, and ultimately resulted in increased surface flooding (urban flooding).

Inadequate Stormwater Management Criteria: Local criteria and design standards for stormwater infrastructure do not always address flooding from large rainfall events. Since storm drain systems are typically designed only for two-year to 10-year rainfall events, rainfall exceeding storm drain capacity must travel overland (on the surface) of drainage basins. Local criteria frequently account for this by specifying maximum flood depths for streets, but this is a more recent regulatory development in stormwater criteria and does not address preexisting or historic development. In other cases, sizing of stormwater systems to meet street conveyance capacity may be deemed too expensive or technically infeasible, leaving behind residual flood hazards during and in the aftermath of larger storm events.

Increased Impervious Surfaces (Development) Upstream of Existing Stormwater Conveyance Systems: As development occurs upstream, within watersheds, runoff increases due to increases in imperviousness and decreases in infiltration. These runoff increases are not always considered in stormwater regulations and criteria, and typically were not accounted for in historic infrastructure construction.

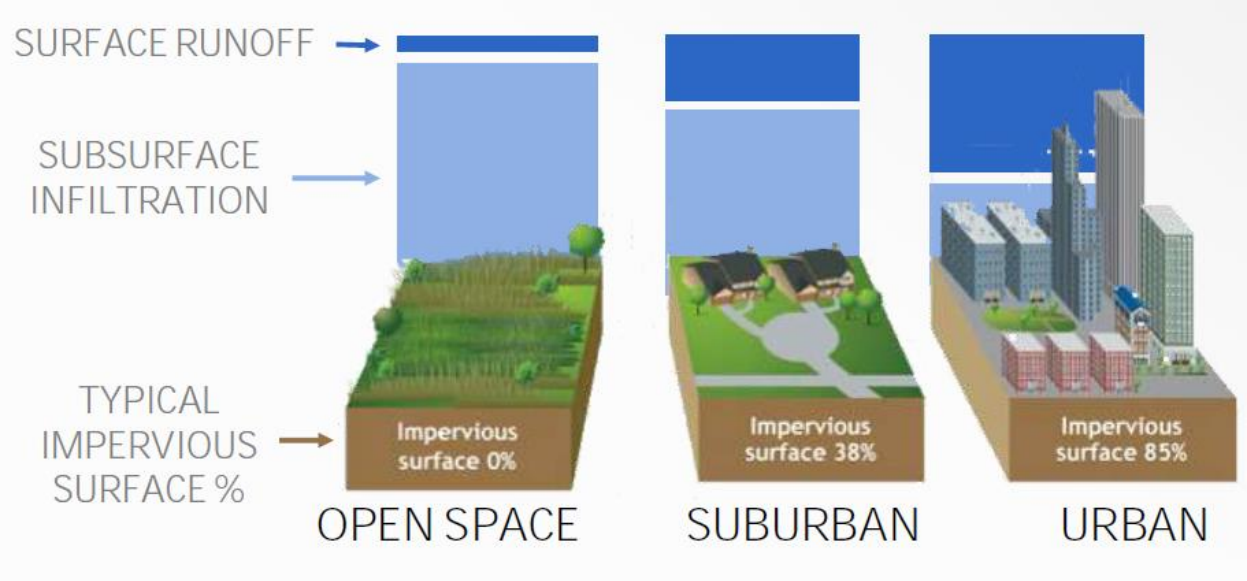

Figure 2. In more urban areas, less stormwater is infiltrated to the subsurface, resulting in greater amounts of surface runoff (Image from Landscapeforlife.org).

Levee Systems and Residual Local Flooding: Where levee systems were designed to keep river flooding out of urban areas, local stormwater can back up on the urbanized side of constructed levees, creating residual flood zones (unless this problem was addressed in the design of the system).

Combined Sewer Systems and Sewer Backups: In many communities east of the Mississippi, combined (sanitary and storm) sewer systems are common. These systems are typically not designed to accommodate all flood events; when these systems are overwhelmed it can cause upstream flooding to structures, particularly basement flooding. In addition, overflows of this type can be in violation of a

community's National Pollutant Discharge Elimination System (NPDES) permit for their treatment facility.

Insufficient Maintenance: Constructed stormwater systems must be maintained to function as designed. Several issues can result in increased flooding and flood risk, including the following:

- Sediment or debris accumulation that reduces the capacity of stormwater management systems and can eventually plug pipes or limit the efficiency of detention/retention facilities.
- Improper maintenance to ditches, e.g., in an unmowed ditch, heavy vegetation reduces the conveyance capacity.
- In some scenarios, landowners mistakenly consider roadside swales or ditches to be located on their property, rather than on a permanent easement, and fill or construct improvements within them. This can cause street flooding or flooding of nearby structures due to a realignment of drainage flowpaths.
- Local agencies may not have infrastructure easements that allow regular maintenance to stormwater systems.
- Storm drain systems may have been installed incorrectly at the time of construction. (Local stormwater management agencies must provide proper oversight during construction to verify correct installation per the design and local construction requirements.)
- If systems are not inspected and repaired, such as backflow prevention valves at discharge points into a river, stormwater will not be able to drain as intended. (Having a consistent maintenance and inspection program and mapping the information can help reduce the risks associated with urban flooding.)

Climate Change: Climate change has altered the intensity and frequency of rainfall events around the globe. In many locations, flooding has become more frequent, and previously constructed stormwater systems can no longer accommodate the rainfall for which they were designed. Climate change is also causing a rise in sea levels, affecting local drainage systems in coastal areas. As sea levels rise, existing stormwater drainage systems may experience backwater effects that reduce conveyance capacity, flooding upstream streets and structures.

UNMAPPED URBAN FLOOD HAZARDS AND UNKNOWN RISK

Unmapped urban flood hazards pose significant unknown risk to the public and property owners. These areas can flood during a variety of rainfall events, resulting in recurring flood damage and repetitive losses. Since urban flood hazards tend to be unmapped, property owners often do not purchase flood insurance and are therefore at risk of incurring significant financial losses. Understanding urban flood risk is imperative to reducing flood losses, as opportunities to improve existing infrastructure and reduce flood risk may be lost during redevelopment within urban corridors. If, for example, a developer does not realize that stormwater flows encroach on their property, they may not take flood depths into account during the development of their site, resulting in post-development flood risk and future flood losses. Unmapped and uninsured risk with the potential for repetitive flood loss makes identifying these flood hazards and educating communities and their government representatives about the associated risks critically important to floodplain administrators and stormwater managers. Flood hazards may remain unmapped for a variety of reasons, including:

- **No Obvious Risk of Flooding:** Urban flood hazards are not always obvious. These flood-prone areas are often in highly developed locations with streets, homes, and businesses, with no apparent natural drainageways or conspicuous stormwater conveyance structures.
- **Status Quo NFIP Mapping Standards:** FEMA does not generally map areas considered local drainage tributaries. FEMA typically starts mapping flood hazards where the upstream watershed area exceeds one square mile. Although many unmapped urban flood hazard areas have watersheds in excess of one square mile, they have no natural drainageways or riverine conveyances, and therefore have not been identified by floodplain managers as locations that require floodplain mapping.
- **Understanding of Existing Infrastructure:** Many communities do not have detailed information regarding existing storm drainage systems. Without this information, detailed evaluations of flood inundation cannot be completed (See Section 3: Specific Challenges Related to Mapping Urban Flood Hazards). There is significant cost associated with collecting detailed information on existing infrastructure; this acts as a barrier to local communities understanding existing urban flood hazards.
- **Identification and Mapping Complexities:** The hydrologic and hydraulic analyses associated with mapping urban flood hazards are complex, requiring the combination of one-dimensional (1-D) pipe system modeling with two-dimensional (2-D) surface modeling. Studies typically required to accurately map these areas can be cost prohibitive.

SECTION 3: OPTIONS TO ADDRESS THE ISSUE

A FRAMEWORK FOR ADDRESSING URBAN FLOODING

Flood hazards in our communities are often best understood by residents and community leaders. Floodplain stewards and stormwater managers face significant challenges in communicating urban flood risk due to the technical challenges and high costs associated with mapping these complex hazard areas. Even when the hazard has been mapped, they may also face internal and external communication challenges in getting the public, senior government leadership, and politicians to acknowledge the associated risk. An additional communication challenge is overcoming a lack of willingness to make flood map information available to the public because of concerns regarding negative perceptions of flood insurance requirements, adverse impacts to property values, and public calls to fix the problem immediately in the absence of adequate government resources. Infrastructure solutions to address urban flood hazards come at significant cost; simply upsizing a stormwater system is often not a viable option when the loss of natural flood conveyance and expansion of upstream development increase the amount and rate of water draining through the system. As storm events increase in frequency and intensity, our communities must be better equipped with the tools to communicate future urban flood risk, and the knowledge and understanding to drive change from the top down as well as the bottom up.

IDENTIFICATION AND MAPPING OF URBAN FLOOD HAZARD AREAS

Identifying flood hazard areas in urban environments comes with a host of challenges. Among these challenges is understanding where urban flood risk exists and to what extent. In the absence of previous studies and mapping, local managers often rely upon anecdotal evidence such as complaint records, photographs, videos, or data showing repetitive flood losses to identify areas with significant flood risk in urban communities. Historically, stormwater master plans or outfall plans have focused on the capacity of piped systems and their ability to meet local conveyance criteria. These plans often reveal that piped systems do not provide adequate capacity to handle large flood events, and residual surface flows were not well understood, or even ignored. Some studies utilize 1-D hydraulic models to predict flood depths and extents. In urban areas, however, stormwater flows are not best modeled in a 1-D environment since flows split at intersections; approximating the volume of stormwater that travels one direction as opposed to another becomes arduous and inexact. From a regulatory perspective, FEMA's reliance on 1-D modeling methodologies hinders accurate mapping of urban flood hazards. In general, 1-D hydraulic modeling programs are not sophisticated enough to accurately analyze overflow flooding in road networks in urban areas. Figure 3 illustrates an urban area that is better suited to 2-D analysis. Knowing the limitations of 1-D modeling, communities may be reticent to request studies to model and map their urban flood hazard, contributing to a resistance to regulate or require insurance in these areas.

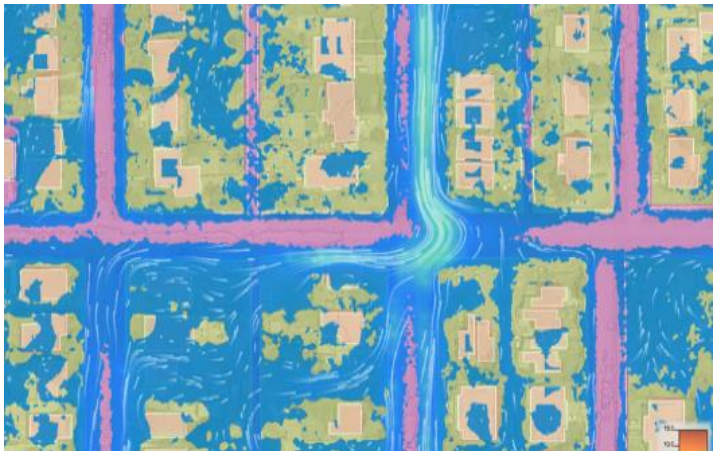

Figure 3. Image of a 2-D rain-on-grid model with GIS layers of houses, roads, and grass separating each feature in the model.

Although 2-D modeling has been available since the mid-1990s, the complexity and cost associated with modeling urban areas and the finite resources of local agencies made such analysis cost-prohibitive, infrequent, or unattainable. Over the past 10 years, however, 2-D modeling has become much more prevalent and accessible to the engineering community, reducing the associated costs. Modern technologies for hydrologic and hydraulic modeling may offer more cost-effective methods to develop large-scale urban inundation maps. Some of these modern technologies are now available at no cost, are user-friendly, and capable of producing more accurate results than their 1-D predecessors. As a result of these more readily available and accessible evaluation and modeling tools, urban inundation maps can be produced with relative ease by a knowledgeable, practicing flood hydraulic professional. However, the level of detail and accuracy varies depending on the available information, such as a comprehensive knowledge of existing stormwater infrastructure.

Specific Challenges Related to Mapping Urban Flood Hazards

Although urban stormwater inundation modeling is becoming less cost-prohibitive and more commonplace, its costs may still exceed the limited resources of many communities around the country. There is also an array of other challenges, both technical and practical, associated with modeling urban flood inundation areas:

1) **Cost and Associated Level of Detail for Flood Modeling and Mapping:** Urban flood hazard modeling can be performed at a variety of levels and costs. Low-resolution modeling to identify flood hazards can be performed at a relatively low cost and in a timely manner. High-resolution modeling requires detailed baseline data, including topographic mapping (typically LiDAR), building footprints, impervious footprints throughout the watershed, soil data, and storm drainage infrastructure information. Not all local agencies have the detailed data necessary to perform complex hydrologic and hydraulic analyses, but there are other options for agencies to consider, including:
    a. **Basic Analysis:** An approximated flooding estimate based on ponding depths at sumps and collected complaint databases. This type of analysis is primarily designed for the identification of urban flood hazards and could not be used for damage estimates or to fully communicate flood risk. Additionally, if detailed soil maps are available, maps showing the limits of alluvial soils where rivers or drainageways used to exist can be a valuable tool for explaining potential flood hazards and the associated risk.
    b. **Better Analysis**: A basic 2-D model with large grids and without building detail or underlying infrastructure connectivity, e.g., storm drain systems. This type of analysis could provide a baseline for determining damage estimates and ponding depths, but may not scientifically support local ordinances or development standards.
    c. **Best Analysis:** A detailed 2-D model that computes both runoff from gridded cells and downstream hydraulics of stormwater flow through a watershed. These models can incorporate building footprints and stormwater infrastructure via a 1-D interface. 2-D rainfall/runoff models can be calibrated to gage data when additional datasets exist, such as gage-adjusted radar rainfall and downstream peak flows. This type of mapping could be used to estimate flood damage and begin to set water surface elevations for enforcing local ordinances requiring minimum first-floor elevations and freeboard. Alternatively, once an existing urban flood hazard area has been delineated, a community may seek to limit discharge from future upstream development to ensure

that it does not worsen flooding, or to improve existing flood conditions and reduce future flood losses.

All of the aforementioned methodologies can assist in the identification of urban flood risk and support the creation of inundation maps that can be used to educate the public and government officials. These analyses can also be used to estimate flood damage within a watershed based on various assumptions about future weather events. This information is critical for decision-makers, especially when considering benefit/cost ratios of alternative strategies.

Urban flooding presents a "new" cost for budgets already strained by maintaining and upgrading legacy systems.

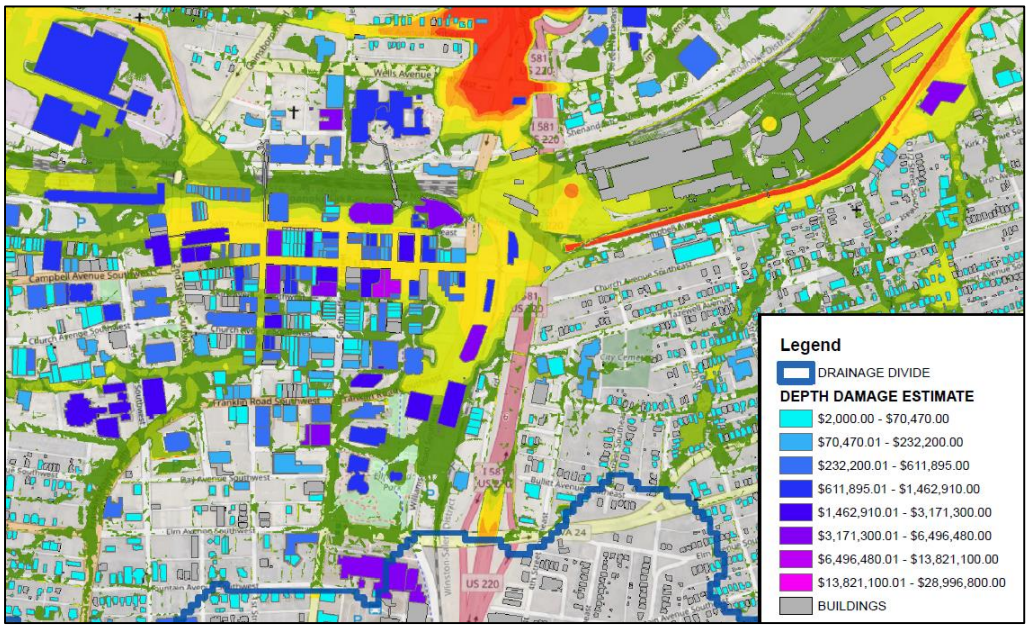

Figure 4. Screen capture of depth damage estimates for buildings affected by an urban flood event

2) **Design Storm Frequencies**: Urban flood damage can (and does) often occur during more frequent events, e.g., the 50%-10% chance (2- to 10- year) storms. Communities must consider a spread of design events up to and beyond the 100-year event in developing an understanding of urban flood inundation areas. In addition, different duration storm events may need to be considered depending on the geographic area and downstream systems.
3) **Federal and Local Management of Urban Flood Hazards:** Many urban flood inundation areas (those outside of riverine and coastal areas) caused by excess surface stormwater runoff remain unmapped by FEMA. Some communities have developed local flood hazard maps for these areas but have not necessarily shared their maps with FEMA to be incorporated into their Flood Insurance Rate Maps (FIRMs) and the NFIP. Choosing to map and make publicly available previously unmapped urban flood hazard zones comes with significant challenges, including:
    a. **Acceptance by the Community That the Risk Exists.** Residents may be aware of flooding within their communities, but the fact that these flood areas are not mapped by FEMA can create suspicion regarding the purpose of non-FIRM urban flood maps. The public may perceive the purpose of mapping to be to justify a capital improvement project that

benefits developers rather than homeowners and residents, or to deny development permits within a flood hazard area. Maps representing inundation areas modeled for large weather events, such as 50-year or 100-year flood events, may be so extensive as to be "hard to believe." Communicating risk beyond annual or semi-annual rainfall events has historically proven challenging for riverine and coastal flooding; urban flooding brings even more nuance to flood risk communication because these areas are not necessarily perceived as flood conveyance areas.

b. **Willingness of Elected Officials to Authorize Sharing of Flood Data Publicly.** Local government agencies may understand that urban flood risk exists, and may have already mapped the hazard area, but the data and mapping may not necessarily be made available to the public. Reasons this mapping may not be made public include:
    i. Once the mapping is made public, residents believe that their property values will be negatively impacted.
    ii. Perceiving that an identified flood hazard will negatively affect property values, homeowners and business owners may demand that the flooding issue be addressed immediately. Unfortunately, the cost associated with directly eliminating these flood hazards – if possible – is great, and most capital improvement budgets are inadequate to address such needs.
    iii. Public perception can create political pressure for action to address these hazard areas, and meeting the costs associated with responsive activities may require unpopular tax increases or the creation of special assessment districts to address urban flooding. Where funding mechanisms can be identified and implemented, the improvement projects – where feasible – are unlikely to be expedient.

If a local government agency can successfully navigate making the inundation data publicly available, the next question is whether the mapping should be regulatory, e.g., included under the NFIP and shown on FIRMs, or enforced by higher regulatory standards under a local ordinance. The positive outcome of making these maps regulatory is that the flood risk will be better understood and communicated with the public, and private property owners may insure against future flood events. Potential negative outcomes may include decreased property values in these areas, and a lack of affordable flood insurance available to property owners in areas identified as high-risk. Regulatory maps may also remove leverage for local communities to address their urban flood hazards. For example, if flood risk is communicated to the public and alternatives to address the flooding, including mapping the area as a regulatory special flood hazard area, are fully understood, residents may prefer to pool what resources might have gone to future flood insurance premiums and instead funnel that money towards infrastructure improvements to mitigate the flood problem. If the risk is mapped as regulatory, incentives and opportunity to address the problem may be lost.

Directing resources towards mitigation may ultimately lead to more resilient communities and reduce future flood losses. As communities assess, identify, and plan to address their urban flood hazard, it's important to remember that different communities have diverse values, goals, and objectives and may choose to address their problems differently, but in a way that fits their

vision of the future. Whatever the approach, community understanding of the risk and concerted action to address the hazard are positive steps towards resilience.

Another potential challenge of creating regulatory mapping of these urban inundation areas is map updates. Urban areas, by their nature, see physical change on a regular basis. For example, public works departments maintain streets and routinely implement pavement overlays. In addition, stormwater management improvements can be constructed locally or upstream within a basin that may directly impact the amount of flow entering a known hazard area. For an area included in a FEMA FIRM, this would require that a Conditional Letter of Map Revision be completed, followed by a Letter of Map Revision. Thus, in creating NFIP regulatory maps, local municipalities would face increased costs for maintenance of floodplain maps, stressing already underfunded public works Capital Improvement Project (CIP) budgets. This issue may potentially be addressed by establishing comprehensive mapping standards, but in all likelihood, communities would expend more of their stormwater or floodplain management budgets on updating these regulatory maps.

4) **Best Practices for Studies and Mapping**: As previously noted, the costs of mapping these urban flood hazard areas have historically been prohibitive, but the entry point for mapping is decreasing on an annual basis. The mapping produced in urban flood hazard areas typically involves 2-D modeling with numerous split flows at roadway intersections. Flood depths are impacted by urban street features such as medians, curbs, raised crosswalks, traffic calming devices, and other related impervious transportation infrastructure. Future development or redevelopment of these areas also directly impacts flood depths. New building footprints displace water, increasing depths or velocities elsewhere within the basin. How to best update inundation maps of these ever-changing urban environments is an unanswered question. Other questions related to mapping include:
    a. Whether to incorporate underground stormwater infrastructure designed for more frequent flood events. Including infrastructure increases model complexity and associated analysis and mapping costs.
    b. Whether stormwater infrastructure is dependable to convey the water it is designed to convey if, for example, inlets or pipe systems become clogged. Conservative analyses may not consider underground systems for large events such as the 100-year flood but choose to include infrastructure up to a certain flood frequency.
    c. What will trigger the need for a mapping update?

Rather than creating restrictive and costly regulatory standards, modeling and mapping best practices that improve study outcomes and provide consistent evaluations should be developed. These best practices or guidelines should be flexible and consider the cost implications to local governments; they should be designed to encourage the mapping and understanding of flood risk rather than to create a set of overwhelming or hard to implement rules and standards that make responsible preventative actions cost-prohibitive.

CHALLENGES IN RISK COMMUNICATION AND EDUCATION

Risk communication and education move to the forefront following disasters in urban flood hazard areas. Events such as Superstorm Sandy in 2012, which decimated the East Coast, and Hurricane Harvey

in 2017, which flooded large parts of Houston, grab lawmakers' and media's attention in the subsequent days and weeks. These events are significant because they shine a spotlight on flood issues plaguing urban areas on a national level and provide an opportunity for other urban communities to discuss how these same issues are also present in their communities. The problem has always been how local communities leverage that support into long-standing policy change and program initiatives after national and local attention wanes. Many communities have taken advantage of such opportunities to develop urban flood risk messaging and established their own risk communication and outreach initiatives.

Outreach and Communication with the Public

Communicating urban flood risk to the public presents many challenges, including:

1) **A Willingness on the Part of Local Officials to Make Flood Hazard Data Available**. As noted in the section on determining urban flood risk, although staff at local government agencies understand that flood risk exists and may have already mapped that risk, the data and mapping is typically unavailable to the public. Informing the public of the existing flood risk is sure to create unrest with watershed residents who have concerns about safety, property values, the potential cost of insurance premiums, and the expectation that someone address and eliminate the flood risk. Many local governments have chosen to make flood mapping data, including modeling, available to the development community on an as-needed basis, but not necessarily to the public. Some communities are concerned that making this data publicly available would trigger FEMA to incorporate the mapping into NFIP FIRMs, limiting their future options to address the risk. The primary reason for not sharing flood risk mapping is the anticipation of public outcry. Communicating new understandings of flood risk requires intentional and well thought-out strategies within a framework to address the problem. This planning framework must consider implementation of capital improvements or strategic modifications to ordinances/regulations that begin to address the problem. Communication of flood risk outside of a framework for dealing with the issue leaves residents feeling uncertain and helpless about their future.
2) **Belief by the Public That the Hazard and Associated Risk Exist.** The best flood maps detailing flood depths for various flood frequencies and depth-damage estimates do not immediately convince the public that a flood hazard exists. The public often views new hazard mapping with distrust. They may suspect that the underlying motivation for identifying this new hazard is to make room for new development or to devalue property in order to buy land for future projects such as parks or government facilities. Although many residents within a watershed may acknowledge that flooding regularly occurs, they fear the outcome of mapping that identifies their home as belonging to an area that frequently floods. Every local municipality attempting to communicate about urban flooding risk faces questions and concerns, such as, "How will this affect my property value? Is my home safe? Why hasn't my local government addressed this problem?" and, "FEMA doesn't identify this as a floodplain, so it cannot be a real flood risk." Communication of urban flood risk must start with the basics, including how the flood risk arose in the first place.

   One invaluable tool for local administrators in communicating existing risk is historical evidence. Many urban flood hazard areas have a long-standing history of flooding. Researching the

archives from local newspapers may reveal years of flood history that can assist in convincing the public that flood risk does indeed exist (see Figure 5). Also, for future reference, it's important that local stormwater and floodplain managers capture news articles, videos, and documentation regarding any flooding within their community since these documents may be challenging to find (or unavailable) years later.

Million Dollars Damage Done by Floods in Denver

-ROCKY MOUNTAIN NEWS— Denver, Colo., Friday, July 10, 1953

This is Colorado blvd. at E. 12th ave. a few minutes after 5 p. m. yesterday. Most of the hopelessly stuck cars have already been abandoned, their riders seeking whatever shelter they could find. A few minutes later, another wall of water from the east hit the cars, scattering them up on lawns.

—Rocky Mountain News Photo by Dick Davis.

Figure 5. A copy of an article in the Rocky Mountain News from 1953 regarding flooding in the Montclair Drainage Basin. Additional research turned up articles from 1912, 1950, 2004, and 2011 for the same area. (Source: Colorado History Museum).

3) **An Understanding of the Cause.** Since urban flood hazard areas are not as readily recognized as those in riverine and coastal areas, a historical review is required to educate the public about why the hazard exists. Explaining the history of how a city developed and the decisions that were made regarding development is critical to that understanding. Sharing historical maps of the community prior to development can help enlighten residents that before development low-lying areas used to be natural floodplains that conveyed runoff. Historical maps may include soil maps that indicate where streambeds previously existed, drainageway maps developed prior to development (see Figure 6), or city planning or plat maps that show how development occurred over time and when natural drainages were filled in and/or replaced by stormwater infrastructure such as closed conduit pipe systems.

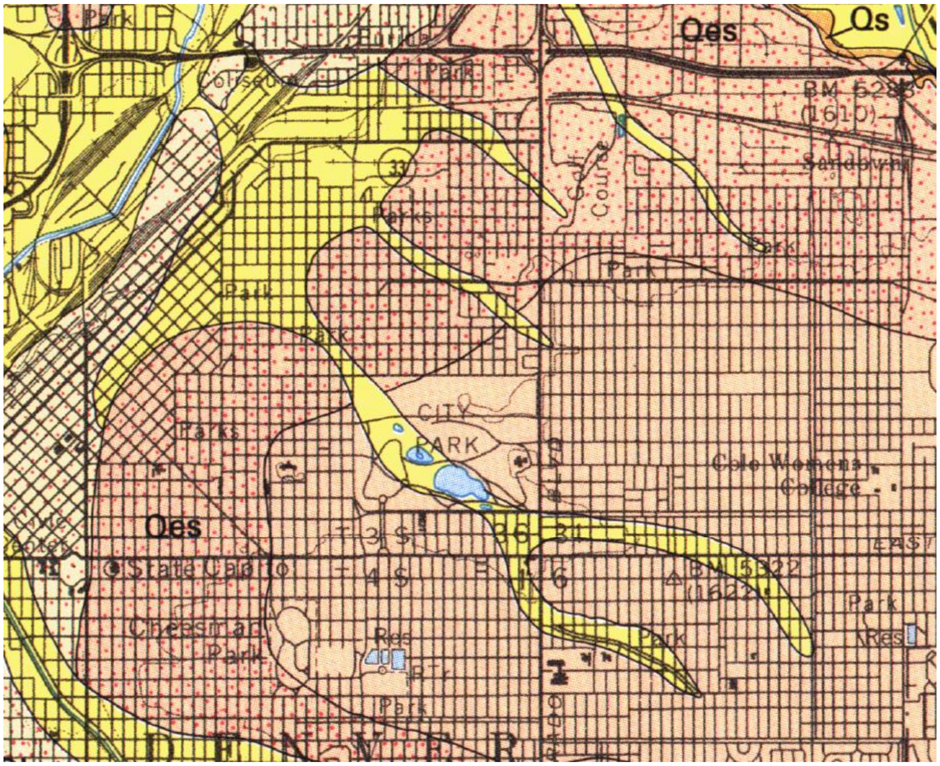

Figure 6. USGS soil map within the City and County of Denver showing alluvial stream deposits where historic drainageways used to exist.

4) **Why the Issue Has Not Been Addressed by the Local Government Agency.** Once residents understand and accept the reality that urban flood risk does indeed exist, the next question that invariably will be asked is, “Why hasn’t the issue been addressed by my local government?” This is an even more problematic issue when a local stormwater utility fee exists, and the perception is that these types of issues should have been addressed using those monies. Government officials must often explain that routine maintenance and replacement of existing stormwater infrastructure consumes almost all of the available funding each year. Although capital improvements are identified in master plans, typically, the implementation of those plans is spread out over decades. On top of that, most local stormwater master plans address conveyance for two to 10-year events and don’t directly address larger, less frequent flooding. Communication strategies to address this question must focus on what an agency is primarily tasked to do on an annual basis and the realities of available funding. In many cases, addressing urban flood hazard areas may require special districts or additional tax levies and municipal bonds due to the complexity and cost of addressing the specific problem.
5) **What Living in These Areas Means for the Local Residents.** Residents who are educated about urban flooding want to understand the implications for them. Specifically, they want to know whether they are at risk, whether they need to purchase insurance, what local government is doing to address the flooding, and what they can do to address the problem. Therefore, communicating risk in a framework of planning and mitigation is critically important; i.e., only mapping the risk leaves the burden on local residents, whereas involvement with planning and mitigation provides hope that the problem can be addressed, whether now or in the future.

PLANNING AND IMPLEMENTATION STRATEGIES

Developing solutions to address urban flood risk is best addressed via a comprehensive and collaborative planning process that considers:

- Risk identification and mapping
- Risk education and outreach
- Community goals and objectives and a strategic framework
- Investigation, identification, and evaluation of solutions
    - Infrastructure solutions
    - Non-structural, planning, and regulatory solutions
- Development of a strategic implementation plan and community toolbox

The development of a comprehensive plan is the crucial first step in addressing urban flooding, educating the public, and providing data and analysis to support proactive community action. A comprehensive plan not only considers infrastructure solutions, it also seeks to evaluate management and regulatory actions that the community can take either in parallel with or separately from proposed capital projects. Nearly all problems in urban stormwater management are the result of land use and development policies and practice – or the unfortunate lack thereof. Gilbert White's maxim that "Floods are 'acts of God,' but flood losses are largely acts of man" is particularly instructive for planning. Water finds a way to flow (down the path of least resistance), regardless of whether that area is developed or in a natural state. Human-scale disasters most frequently occur in areas where land is developed.

Plans are informed by public outreach and participation, and planners have much to learn from residents, businesses, property owners, and other citizens. When design professionals lack information about stormwater and runoff problems, they can seek public input to gain a better sense of stormwater problems. In many cases, those who live, work, and play in a community are more familiar with drainage problems, nuisance flooding, and local topography than are professionals working with those issues conceptually. However, knowledgeable members of the public may not be engaged or share their insights.

A Collaborative Team

In order to deliver a comprehensive, collaborative, and resilient plan to address urban flood risk, the right professionals must participate and lead the effort. Often, stormwater or drainageway planning efforts have been the realm of engineers, who have focused on gray infrastructure solutions, building on the hydrologic and hydraulic analyses that determine the quantity and extent of flooding in an area of interest. Communities must now move beyond that model and ensure that teams are made up of specialists with expertise in:

- Planning and education
- Public outreach and involvement (including interaction with elected officials)
- Urban design and planning
- Landscape architecture
- Hydrologic and hydraulic modeling
- Stormwater systems design
- Transportation systems

- Ecosystem evaluations
- Finance and development

The above list is only a starting place, and additional expertise is likely needed and warranted depending on the scope of a given project, e.g., lawyers and experts in private-public partnerships may provide critical expertise for implementing ordinances and financing future improvements. The key takeaway is that addressing urban flood risk in a resilient fashion requires a team of professionals of varying expertise rather than a specialized group of engineers.

Risk Identification and Mapping

Mapping and identification of urban flood inundation areas should be the first step in any community's action plan to address urban flood risk. As previously mentioned, inundation areas are typically known, at least anecdotally, via complaints databases, maintenance crew observations, or news reports from previous storm events. Once a community has determined that they have one or more hazard area, they can start the process of budgeting for a more detailed analysis that provides mapping of the areas at risk. It's important for local managers to discuss this process with local elected officials at the front end of risk identification so as not to "surprise" anyone as risk becomes better identified. Throughout the country, many areas have been mapped through local programs without publicly sharing the results due to the fear of public outcry and lack of a plan to address the problem. This is why it is important to have a full planning process that includes the support of elected officials in place before beginning education and outreach actions.

Risk Education and Outreach

Preparing to Share Urban Flood Inundation Maps with the Public

Simple inundation maps often do not provide a complete understanding of flood risk for citizens or even other planning professionals. At the start of the inundation mapping efforts for urban flood risk, city managers, engineers, and planners should discuss producing work products that better inform and educate the public regarding flood risk. Questions that should be asked may include:

- **How Can We Explain What Caused This Problem?** Taking the time to show the history of the city, including historic development over time is beneficial for the public. Questions to consider are: What did this area look like prior to development? When did development occur? What was the thought process regarding stormwater and drainage at the time of historic development? What has occurred upstream since that time?
- **How Might This Problem Have Been Avoided?** This is a good opportunity to show how current land development regulations prevent the filling of natural drainageways and/or limit discharge from development to that of pre-development conditions. This is also a good time to show a timeline of when stormwater rules and regulations were developed and implemented.
- **How Often Will Flooding Directly Impact Citizens?** Providing inundation maps for a variety of runoff events helps alert citizens to the expected flood frequency.
- **How Much Damage Can Be Expected When It Floods?** In combination with inundation maps, developing depth-damage estimates for a variety of events begins to establish the serious nature of the problem and why it needs to be addressed.

- **What Is the Plan to Address the Problem?** It's important that citizens understand that the mapping effort is only the beginning of the planning process in which they will participate. Reassuring them that they will have the opportunity to participate in developing solutions gives them ownership in the process. Improvements to address urban flood hazards are typically very large in scale, and often the implementation plan is phased. It's important to communicate the incremental results of each phase and explain that the completion of a watershed-wide solution that fully addresses the flood problem may take several years.
- **What Can Be Done Right Now?** It's wise to share with citizens and managers that although construction of an infrastructure solution may not be immediately possible, there are proactive actions that can be taken now. These actions include purchasing Preferred Risk Policies through the NFIP, as well as the development of local ordinances and regulations to ensure that the situation doesn't worsen with new development.

The stormwater manager and risk communication team should prepare a full presentation with figures, charts and graphs, mapping, and factsheets to answer the questions above (as well as several others) prior to presenting risk data to other city managers, elected officials, and citizens. Creativity should be encouraged in thinking about how to connect people to risk data. There are many examples of creative solutions throughout the country. Included below is an example from Toledo, Ohio; it is a web-based tool for visualizing flood data and flood losses on an interactive map.

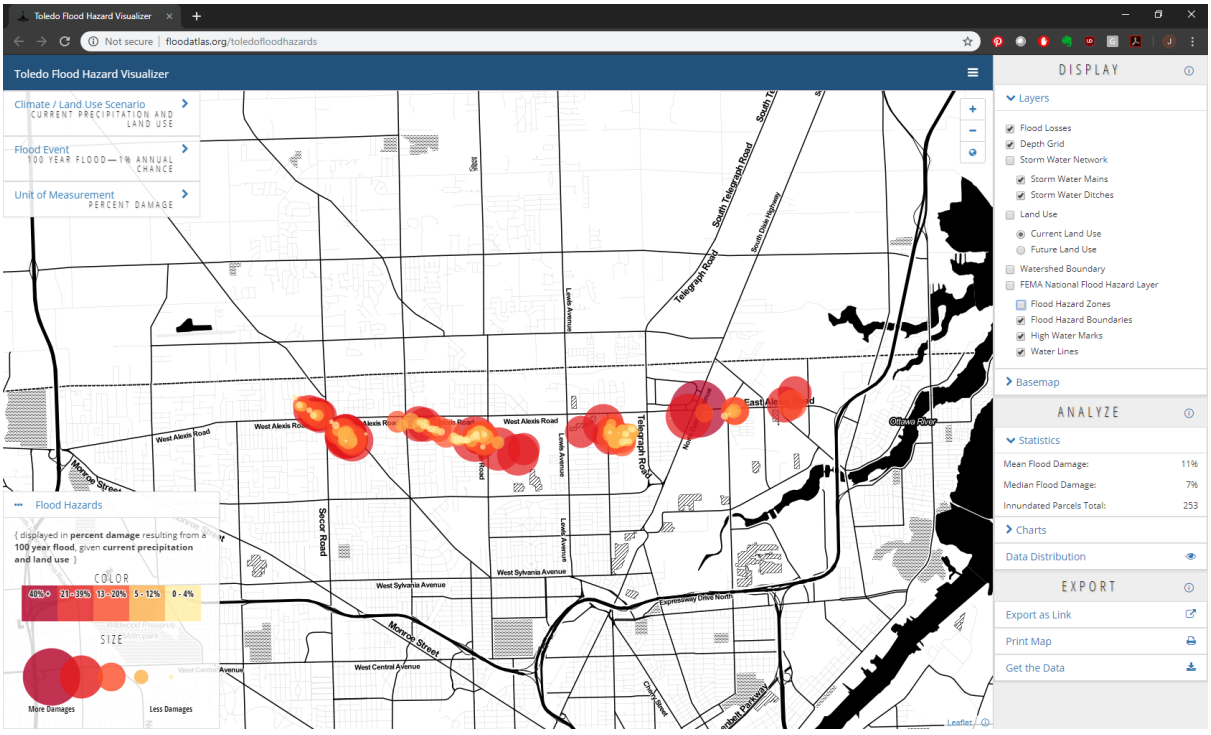

Figure 7. The Toledo Flood Hazard Visualizer providing information regarding flood depths, potential flood losses, and regulatory floodplain data via the internet.

Communication with Municipal Managers

Once the hydrologic and hydraulic analyses have been completed and inundation map(s) generated, a community's staff should meet to thoroughly discuss the issue. Meetings should include transportation

managers, stormwater engineers, city planners, parks and recreation staff, and zoning/development review professionals. The extent of the problem and its effects on city infrastructure should be understood by all departments. The education of various departments regarding urban flood risk is foundational for future planning as a successful plan will address each one of these areas, not only stormwater or flooding. Because of the interconnected nature of a city, any action in one domain affects the function of a different set of infrastructure. By engaging each department, opportunities that were not previously considered may become apparent. For example, a transportation plan may help inform the decision of where stormwater infrastructure may best be placed in the future, or a parks and recreation plan may be integrated into a watershed-wide solution that includes green infrastructure implementation. While educating these departments early on about the extent of the problem is critically important, just as vital is their engagement in the overall planning process and development of goals, objectives, and solutions.

Communication with Elected Officials

Local elected officials and decision makers typically take notice of urban flood risk following large flood events. Depending on geographic location and sensitivity to urban flooding, some communities are likely to remain focused on these issues, e.g., communities at risk from a hurricane. Areas in the arid west, such as Phoenix and Denver, may have a more difficult time maintaining the attention of elected officials when it comes to urban flood risk. Local stormwater and floodplain managers should take every opportunity to educate officials and other influencers regarding the importance of flood risk outreach and communication, and how government regulations and policies impact that mission.

Upon developing the first inundation maps of these areas, it's important to engage and educate local elected officials regarding the problem. Because of the potential outcry from citizens when these areas are mapped, it is best to educate officials on the cause and significance of the problem, and to explain the planning process of addressing urban flood risk. Ultimately, elected officials approve city budgets directly connected to any strategic plans that will be implemented, and their ability to answer questions from their constituents improves relationships and outcomes over time. In other words, elected officials know ahead of time what to expect, and can explain that they have proactively funded the planning process and support the long-term strategic plan developed by their public works staff in partnership with citizens.

Communication and Partnerships with Other Jurisdictions within the Watershed

Many watersheds, both urban and rural, span multiple jurisdictions. This increases the number of challenges that a local stormwater manager faces and limits their ability to directly regulate stormwater runoff that may exacerbate urban flood risk. As local managers educate various departments, elected officials, and the public, they must also reach out to adjacent jurisdictions, both upstream and downstream, in discussing and developing solutions for urban flood risk. Addressing urban flood risk and stormwater runoff requires a multi-jurisdictional approach. Such an approach to address, regulate, or manage stormwater can yield many benefits, including the ability to address water quality and quantity at a watershed scale. In some cases, development may be ongoing in an upstream jurisdiction, and the ability to coordinate may provide the opportunity to address excess stormwater runoff in a way that reduces (or at least does not expand) existing urban flood inundation areas. The development of watershed coalitions, groups comprised of representatives from various watershed stakeholders, is one approach that local managers should consider. These coalitions allow for a broader context in which to

evaluate solutions that benefit all residents in a watershed, while also maintaining a philosophy of "do no harm" when it comes to ongoing and future development. Watershed coalitions have had significant success in Louisiana and Colorado and may provide some guidance for local managers seeking to develop watershed solutions as part of a comprehensive approach to address existing urban flood risk.

Communication with the Public

Due to the challenges previously stated, sharing urban flood risk information with the public requires a well-thought-out strategy and plan to ensure that local residents are not left feeling helpless once the information is shared. It's important that public works and floodplain managers have not only a strategy in place to identify the areas at risk, but also a follow-up set of specific actions to proactively address the identified problems. This is best done through a planning process that starts with one-on-one meetings with community leaders, such as neighborhood groups or homeowners' associations, and builds towards smaller neighborhood meetings, and ultimately larger community meetings. The key to success in this type of outreach is to fully educate the public about the problem, how it came to exist, and what it means to them. Taking the time at the front end of the planning process to allow citizens to absorb the information is incredibly important. Any future improvements will directly affect the places where citizens live, work, and play in terms of construction impacts, land buyouts, right-of-way, community amenities, etc. A successful implementation program begins with community trust building.

Many property owners assume that because their property or neighborhood is located outside of the flood zone, they are immune to the effects of urban flooding. Road closures, infrastructure damage, and limited access to emergency facilities are some of the impacts of urban flooding and should be taken seriously by all residents. Effective communication regarding the impacts urban flood hazards should target everyone within the watershed, not only people living in or near a flood zone. For example, flash flooding at low-flow crossings is a serious issue for residents and local officials in the Phoenix metro area. For much of the year, people drive through low flow crossings without fear of flooding. During the monsoon season, the low flow crossings become a serious hazard since floodwaters rapidly rise in response to flood events. Phoenix and the Flood Control District of Maricopa County post warnings at these crossings and continually remind residents of the flood hazard throughout the year – not only during the monsoon season. Communities may consider the installation of urban flood signage to warn residents and visitors that streets may flood during storm events. Another option is to create a monument on the ground surface showing the primary flowpath of floodwaters through the basin during extreme events to serve as a reminder of the risk of flooding.

Using factsheets, inundation mapping, presentations, and other materials, planners can directly communicate with citizens about urban flood risk. The importance of taking the time to fully educate the public about urban flood risk cannot be understated. Jumping into the planning process before the community understands and takes ownership of the existing problem often leads to a flawed planning process with little to no public buy-in. Since each community may choose to address their urban flood risk differently, building a common understanding is paramount; building on that understanding, a community can then work together to develop goals and objectives that reflect community values. Ultimately, community members must be involved in the planning process from start to finish, from identification of the issue through strategic planning and long-term implementation. The success or failure of any plan is directly related to the amount of community support developed through the process.

Regular and sustained communication with the public about flood risk must continue over time. Throughout and after the planning process, communities should develop communication plans that provide the most up-to-date information on hazards and pending actions. This information may be tied to existing agency websites or may be included on area specific web pages directly related to a specific neighborhood or community. These websites should connect to existing materials such as FloodSmart.gov, which is recognized as having current, accurate information specifically geared towards the public. Communities that successfully communicate urban flood risk use a variety of methods to convey their message; websites, social media, newspapers, and local television are effective ways to deliver information. Personalized messaging for property owners is likely the best way to communicate urban flood risk. Local communities can remind people to ask about their flood risk by presenting at fairs, neighborhood meetings, schools, and events hosted by like-minded organizations such as their state chapter of the Association of State Floodplain Managers. By becoming involved in residents' normal activities, local officials can integrate urban flood hazard messages into their daily lives. Mailouts[1] to inform property owners of changes in their flood risk are also effective. For specialized messaging, such as construction beginning on a new capital improvement project to alleviate flooding or a change in NFIP regulations, news releases in the newspaper or on local television may be required to relay this information to a wide audience.

Unfortunately, the same messages do not always necessarily reach renters in areas affected by urban flooding. Currently, property owners are not required to notify renters of potential flood risk. Some cities in Texas are advocating that the state legislature pass reforms that require property owners to share flood risk information with renters. Local agencies can develop local programs to provide information to the public or provide signs that indicate previous flood elevations in affected neighborhoods. Communities and organizations that provide information to renters include the City and County of Denver and Sacramento County. Other communities can take note of these actions and adopt or modify them to fit their local needs as necessary.

Community Goals and Objectives

Comprehensive planning must not only develop community goals and objectives that address urban flood risk, but also meet the values of the communities at risk. Through a well thought-out, process-driven, and relatively time-unlimited process of public outreach and education, planners can also compile a list of community values that may directly impact the outcome of a comprehensive planning process. This list of values very well may be unrelated to urban flood risk but could affect proposed solutions. Some examples include:

- **Does a Community Desire More Recreation or Parks Space?** This value could lead to solutions that are integrated with green infrastructure or traditional stormwater detention.
- **Is Pedestrian or Bicycle Mobility within the Community a Significant Concern?** This may be an opportunity to connect daylighting of storm drain systems with mobility solutions such as recreation paths along greenways.

[1] Metro Denver's Urban Drainage and Flood Control District sends a postcard to all property owners that are affected by changes in flood studies that may impact their flood hazard designation on the FIRMs. Property owners receive a postcard informing them if their flood risk has changed or remains the same.

- **How Does the Current Land Use within a Neighborhood Best Meet the Needs of Citizens?** The values of the community may indicate that commercial development is not highly desirable. Alternatively, a community might determine that small commercial development connected by high mobility corridors could improve quality of life and reduce the need for driving.
- **Does the Current Transportation Network Meet Future Needs?** Varying street networks may provide the opportunity to address urban flood risk in unique and creative ways and/or at least provide new corridors for pipe or stormwater infrastructure.
- **Is Water Quality a Concern?** Communities that are directly concerned with water quality may determine that green infrastructure solutions are preferred as part of the long-term strategic plan. Additionally, these values could affect rules and regulations regarding future infill development.

The list of community values and priorities is almost endless. Thus, a planning team endeavoring to complete a comprehensive plan to address urban flood risk must start by determining a community's values and then integrate those with the goals and objectives that guide the alternatives development and overall planning process. As a starting place, the following guiding principles may be incorporated into the planning process to address urban flood risk:

- To minimize the impact of flooding associated with minor to moderate storm events
- To think critically and creatively about stormwater resiliency in a built, urban environment
- To increase the role of public education and awareness in adapting to flood conditions in the built environment
- To examine basin characteristics as a test-case basin in order to identify implementable strategies that support a resilient community

Ultimately, community engagement at multiple levels will determine the success of the plans developed to address urban flood risk. Developing an overall engagement plan that creates local ownership and understanding and establishes a systematic method of collaboration throughout the planning process is an important first step. Some suggested engagement strategies might include:

- Approaching neighborhoods with consistent, transparent, and responsive messaging and materials
- Creating opportunities for citizens to engage and collaborate with one another
- Convening a basin advisory group or working group that advises the municipality on water-related and community issues
- Coordinating with the local business community

Investigate, Identify, and Evaluate Solutions

Historically, stormwater and floodplain management master plans have focused on infrastructure-heavy solutions. Alternative screening often considers variations of the following:

- Status quo – maintaining existing conditions
- Conveyance/capacity improvements
- Restoration of the natural waterway
- Detention and/or water quality improvements
- Acquisition of flood-prone properties

- Non-structural measures

While these alternatives are still valid and should be considered as part of every planning process, communities will want to consider how these alternatives integrate with their values and the goals and objectives developed at the front end of the planning process. Potential "add-on" considerations may include:

- Creation of new parks or open space in combination with acquisition of flood-prone properties
- Incorporation of green infrastructure on a local or regional scale that could affect streetscapes
- Development of new greenway corridors in combination with restoration of natural drainageways
- Restructuring of transportation networks or crossings to create grade-separated crossings for pedestrians and cyclists
- Development of local land use regulations and ordinances as part of non-structural measures to limit or control development in a way that causes no adverse impact to existing flood risk
- Flood risk zone mapping and/or special district assessments to help assist with future improvements

A planner's toolbox is almost unlimited, but must be informed by a community's desires and vision for the future. The following sections briefly discuss infrastructure solutions and local land use regulations for planners, engineers, and managers addressing their urban flood risk to consider. Also, because of the scale of improvements often required in areas of high urban flood risk, it's important to communicate to the public that it may take significant time to implement a full watershed level solution, i.e., one project is likely not going to solve the current urban flood risk issue. Explaining that there are multiple levels of implementation, starting at the individual homeowner level (floodproofing and property improvements), and moving up to the neighborhood level (neighborhood projects), and ultimately the watershed/basin level (full-blown stormwater specific capital projects), will help citizens understand how improvements help to fix the problems that exist as a strategic plan is implemented.

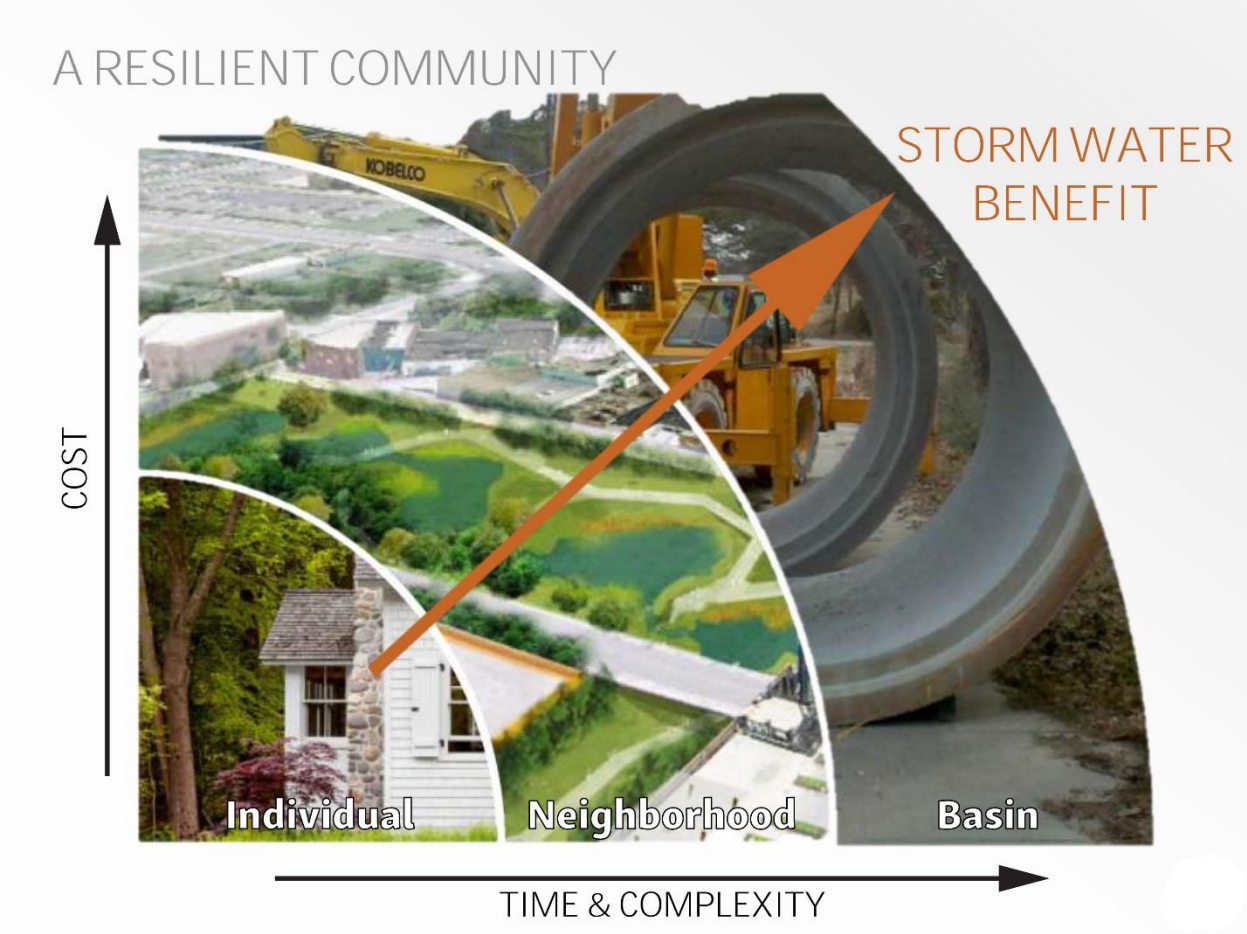

Figure 8. Graphic showing how a resilient community might address urban flood risk starting at the individual level up through watershed solutions and how time, complexity, and cost increase at the various levels.

Potential Capital Improvements to Address Urban Flood Hazard Areas

Upgrading or replacing stormwater infrastructure to address urban flood risk almost always requires significant expenditure. These costs vary greatly based on the size of the watershed and whether the facilities are located within areas that were previously developed. For previously developed areas, such as those affected by urban flood risk, adding pipes to address runoff from upstream or infill development after little or no standards have been in place for decades can be extremely costly, if not unattainable. Local managers face the daunting tasks of establishing a need for such facilities, developing an adequate plan to address the urban flood risk, and providing justification for the associated costs.

Communities faced with addressing existing urban flood hazards have a variety of potential infrastructure improvements that they can use to mitigate the existing risk to structures and emergency access.

Increase the Size and Capacity of Existing Stormwater Infrastructure: Through the planning process, communities may determine that replacing or adding to existing stormwater infrastructure could reduce the impacts of urban flood inundation. Under this option, communities either replace existing pipes or

channels with larger ones with greater flow capacity or add parallel systems that convey additional stormwater runoff.

Daylighting/Drainageway Restoration: This approach restores a natural conveyance system that was previously filled in and/or converted to a piped conveyance system. The benefits of this type of solution include a return to a more natural flood conveyance system with more capacity than a piped system, the opportunity to provide community amenities such as trails and recreation areas, improved or recreated ecological function, and improved water quality.

Stormwater Detention/Retention: This is a traditional engineering strategy that seeks to store excess urban runoff, releasing runoff at historic peak rates. These facilities can reduce the peak flow rates entering downstream locations where existing stormwater infrastructure may be undersized or unable to handle large storm events.

Green Infrastructure or Low Impact Development: Green infrastructure and low impact development manage stormwater runoff via infiltration, mimicking natural systems that existed prior to development. These systems reduce peak runoff rates and volumes, increase infiltration and groundwater recharge, increase evapotranspiration, and reduce pollutants in-situ. There are many recent examples of cities around the world investing heavily in green infrastructure to address excess urban runoff, including cities in Singapore and China.

Property Buyouts and Greenway Development: Cities may consider purchasing properties within urban flood hazard inundation areas as an alternative to new stormwater infrastructure. In some cases, buyouts may prove to be more cost-effective than new infrastructure. Buyouts provide the opportunity for new public amenities such as parks or green space, and/or may also be used to implement green infrastructure strategies.

All of these infrastructure solutions should be informed by other community plans related to transportation, mobility plans, parks and recreation, major utilities, and land use. Taking the time to ensure compatibility with future plans, community values, and goals and objectives to address flood risk will ultimately result in a plan that has greater odds of implementation success.

Cost

Costs to implement infrastructure solutions to address urban flooding can be significant and potentially unattainable. When considering infrastructure solutions, it's important to develop a comprehensive benefit/cost analysis that can be used to make data-driven decisions. To support this type of analysis, depth-damage estimates for a full range of storm events is critically important. Understanding the frequency and cost of flood damage should be a part of the inundation mapping effort on the front end of the planning process. The currently established methodology per FEMA Benefit-Cost Analysis (BCA) is to assess damage using USACE Depth-Damage Function (DDF) Curves. DDF curves assign a percentage of damage relative to the depth of flooding and the value of the building and its contents. Although this approach can provide a good starting point for assessing damage, it does not allow for assessment of the many tangential costs of delivery of disaster recovery programs. It also doesn't consider benefits directly related to community values or lifestyle.

As an add-on to simply evaluating depth-damage estimates as part of the benefit-cost analysis, planners may also consider assigning value to ecosystem services (including water quality, ecology, and stream

function), overall health within a community that is active vs. inactive, and values of homes within a community as affected by local amenities. Additionally, some indirect economic benefits may include social cohesion, public safety and traffic reduction, mental health benefits from green space, and social equity considerations. How does one quantify ecosystem services benefits? It largely depends on the priorities and regulatory atmosphere of the community. The ability of a community to quantify this cost is very different in a community with a high degree of state and federal oversight than in a community that is mostly self-regulated. For example, a community in Washington State is going to have more value associated with salmonid habitat preservation than a community in Texas where stormwater quality permits are mostly written and enforced at a community level with very little state oversight. Through the planning process and as alternatives are developed, depth-damage estimates must be revised to understand the mitigation benefit of each proposed solution. Developed alternatives should include multiple scenarios, with different levels of protection and long-term benefits, future maintenance considerations, and a buyout option that includes demolition and relocation.

Finally, communities should consider multi-generational timeframes for benefit-cost analysis. Where urban flood risk exists and isn't addressed, flood damage will continue to occur for generations, and at escalating costs due to inflationary pressures. Large-scale projects that mitigate flooding for large storm events create a more resilient community, virtually freeing future generations from dealing with costly flooding.

Non-structural, Planning, and Regulatory Solutions

During the planning process and in working with community leaders, non-structural and regulatory solutions to address urban flooding should also be considered. If they haven't done so already, communities should adopt criteria and regulations regarding new development in the upstream watershed limiting site runoff to historic conditions. Additional regulations and non-structural solutions that should be considered include:

Local Floodplain Ordinances. Although urban flood inundation areas may not be mapped under the NFIP, nothing prevents communities from mapping and regulating these hazard areas. The City and County of Denver has mapped the urban flood risk and designates these areas as Potential Areas of Inundation (PIA). In these areas, the city has detailed 2-D hydraulic modeling and water surface elevation estimates. New development must be constructed so that the first-floor elevation is either a minimum of 12" above the 100-year Water Surface Elevation (WSEL), or above twice the value of the 100-year flow WSEL (see Figure 9).

The City of Fort Worth, Texas recently developed a local floodplain management policy designed to amend the city's existing Floodplain Provisions Ordinance, Subdivision Ordinance, Stormwater Criteria Manual, Comprehensive Plan, and other applicable city codes to establish a consistent method for reducing flood damage that occurs in areas outside of current city regulatory floodplains, specifically urban flood hazard areas. That policy sought to address two key areas:

- Areas of Potential High Water (APHW) – [Advisory] Areas located generally upstream of city regulatory floodplains. Created for planning efforts, this product indicates that stormwater runoff accumulates to a depth of six inches or greater due to concentration of flow and obstructions based on topography.

- Local Floodplains (LF) – [Regulatory] Areas located generally upstream of city regulatory floodplains, where detailed engineering studies prepared for specific basins consistent with Fort Worth Stormwater Criteria Manual standards indicate that stormwater runoff accumulates to any depth.

Managers may also consider different requirements for critical facilities, e.g., a larger freeboard or higher first-floor elevation for critical facilities such as hospitals or emergency response services.

The purpose of these types of ordinances is to reduce flood losses in areas outside the city regulatory floodplains by establishing consistent development guidelines managed with local resources. The key components in reducing flood losses through these ordinances are mapping the risk areas, communicating the risk to end users, and regulating how development occurs in risk-prone areas.

No Adverse Impact. Communities should specify that in areas of urban flood risk, any new development must not cause any adverse impact to other structures or public right-of-way. Practically, this means that new development would not cause any rise in WSEL on nearby structures and wouldn't result in increased depths within the street right-of-way for emergency access considerations.

Insurance. Where urban flood risk exists, communities should encourage their constituents to obtain flood insurance from the NFIP. As originally noted, urban flooding has many causes such as overland ponding, inadequate sewer capacity, basement backups, and overbank flooding. Since typical homeowner insurance policies do not insure against flood losses, homeowners should consider purchasing flood insurance and additional relevant endorsements, e.g., a basement backup endorsement. Property owners should consider a holistic insurance approach to insure properties against flood damage. Different types of water intrusion are covered by different insurance policies. For example, a basement backup endorsement may cover the loss caused by sewer backups, whereas a flood insurance policy covers against flood losses. The insurance premiums for these areas are often less expensive than for properties within SFHAs.

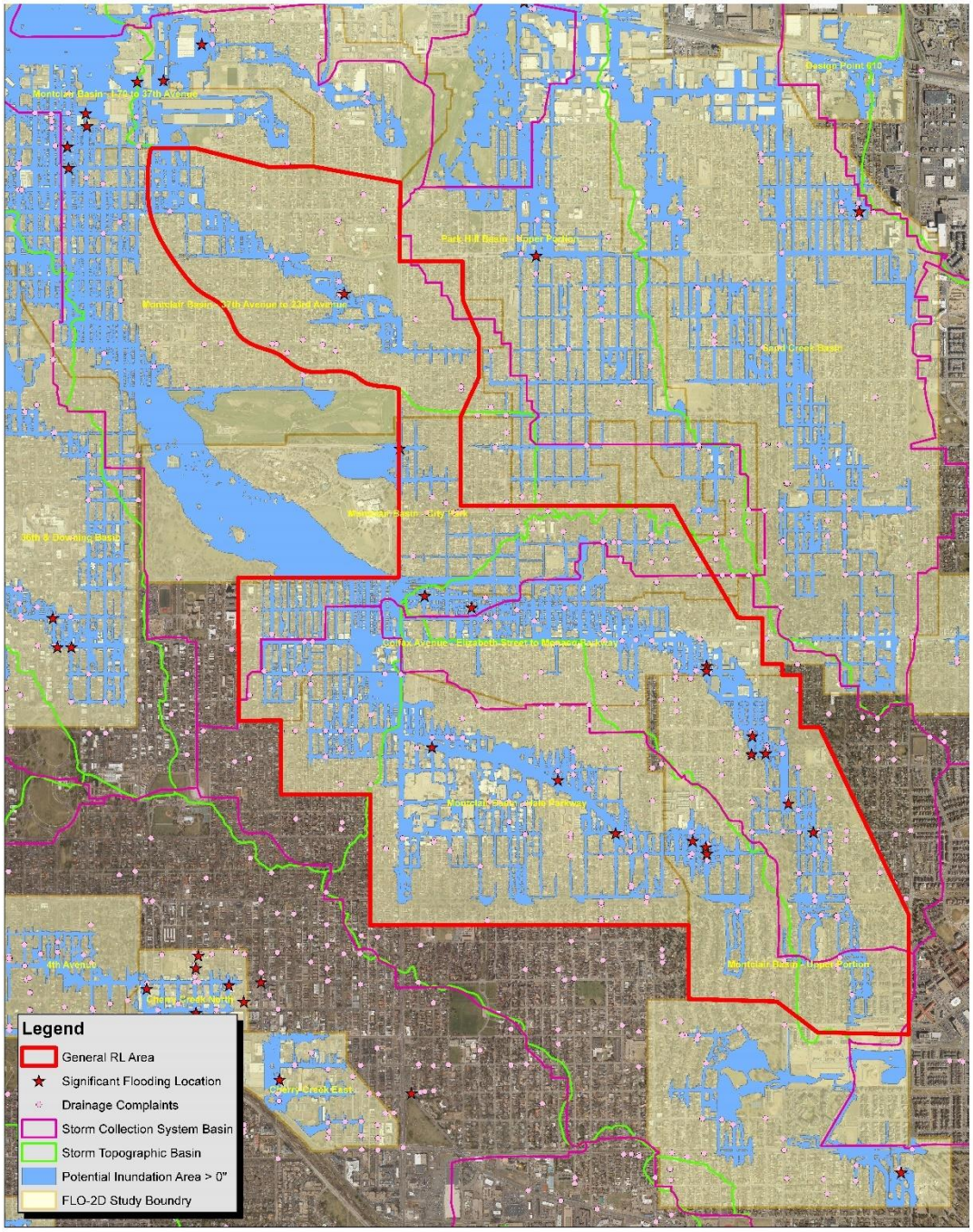

Figure 9. A Repetitive Loss Drainage Map used to regulate Urban Flood Hazard Areas within the City and County of Denver. This mapping was based on 2D hydraulic modeling developed during city-wide stormwater master planning efforts. The map depicts the estimated flood boundaries. Detailed depths and water surface elevations are housed in the city's GIS database for use by development review staff.

SECTION 4: RECOMMENDATIONS

THE PATH FORWARD: RISK IDENTIFICATION, COMMUNICATION, AND MITIGATION

Recommendation 1: Identify and Map Urban Flood Hazard Areas

Although many stormwater and floodplain managers know there are highly developed areas that flood on a regular basis and cause flood damage within their communities, these areas often remain unmapped and not completely understood. It's imperative that local communities understand the current risk of flooding in unmapped urban areas. Floodplain managers at various levels across the country must take action to map these areas. These actions should include:

- Local communities should set aside funds to study and map urban flood risk. As funding for risk mapping at the federal level is often limited and/or already obligated to map other risks such as riverine and coastal flooding, communities should determine how local funds can be generated to support risk mapping and planning.
- Federal government agencies and state agencies should consider the creation of an incentive-based model to fund mapping and mitigation.
- Federal legislators should consider making federal funding available to assist local communities in mapping urban flood risk (not necessarily tied to NFIP mapping). Local communities can better understand their mapping needs and how developed data will be used.
- National organizations such as ASFPM and the National Association of Flood & Stormwater Management Agencies should partner with FEMA and local agencies in developing modeling and mapping best practices and recommendations for urban flooding. Since identifying unmapped flood risk has many significant challenges, not only developing modeling and mapping best practices, but also providing effective policies (model ordinances) for managing newly mapped risk is imperative for local stormwater and floodplain managers.

Recommendation 2: Urban Flood Hazard Areas Must Be Managed at the Local Level

Local communities should lead all efforts associated with urban flooding, including:

- Identification and mapping
- Regulations for development within and upstream of urban flood hazard areas
- Communication of urban flood hazards and associated risk
- Mitigation to address flood risk

Communities want to be able to provide creative and comprehensive solutions to their urban flooding issues and prefer that these areas not be included in FEMA's SFHA. It's a common thread amongst local managers that they feel that more options exist for them to address urban flooding constructively when flood hazards are managed locally.

Recommendation 3: Communicate Urban Flood Hazards and Risk

Inform the public that not all flood risk is mapped or understood. Citizens outside of SFHAs believe that there is no real flood risk to them or their property because NFIP maps do not show flood risk in many non-riverine, non-coastal urban areas. Communicating this hidden flood risk through programs such as

FloodSmart, state agencies, and local agencies should be a priority to insure at-risk homeowners and business owners.

- Communities must communicate with landowners about actual flood risk and recommend the purchase of insurance in areas located outside of the SFHAs, but near unmapped urban flood hazards. As part of this communication and education process, communities should provide a thorough description of the historic and future impacts of development activity at the development site boundary, and cumulative effects of increased runoff farther downstream in the watershed, including how the runoff could affect urban flood hazard areas and stream stability.
- Nationwide best practices for communicating with and educating the public regarding urban flood risk must be developed to be used by local communities as part of comprehensive and collaborative urban flood risk mitigation planning. ASFPM should consider the development of how-to-guides that create a framework for local managers on managing urban flood risk, addressing areas of identification, communication, planning, and implementation. Additionally, success stories, similar to those about the Community Rating System, from around the country could be made available online through the Flood Science Center.
- Communities should create awareness and develop policies to help residents understand how funding and design standards reduce risk, as well as the real value of maintaining infrastructure and their role in supporting these efforts.

Recommendation 4: Develop Local Building Construction Standards

Communities should regulate new development and redevelopment within urban flood inundation areas. In addition to developing standards for elevating new construction above identified flood hazards, communities should anticipate the geophysical impacts that climate change portends – and develop strategies to respond to the variety of human decisions, perceptions, and reactions likely in post-disaster recovery and redevelopment scenarios.

- Local model ordinances should be developed and shared by national organizations such as ASFPM to be used as a starting point for communities addressing urban flood risk. These ordinances should address requirements for identification and mapping of urban flood hazard areas as well as development requirements pertaining to first-floor elevations and freeboard. Additionally, ordinances should consider upstream development with regulations that limit or reduce runoff to downstream urban flood hazards.
- Communities should implement planning that considers pre- and post-disaster strategies and actions. For example, communities may develop buyout programs for properties within urban flood hazard areas and/or combine buyouts with infrastructure creation, e.g., the creation of a new stormwater detention pond on buyout property to reduce downstream impacts. Post-disaster action plans that are vetted by the community may ultimately reduce future losses due to flooding.
- Local agencies may consider modifications to building designs to account for greater runoff frequencies under climate change, e.g., increasing the size of new stormwater infrastructure to convey the 10-year runoff instead of the 5-year event for minor storms, and fully addressing street flooding by not only preventing construction of structures within flood-prone areas, but also ensuring emergency vehicle access during flood events.

Recommendation 5: Employ Multi-Generational Approaches to Implementing Improvements

Communities should consider long-term planning in urban flood zones that prioritizes buyouts of flood-prone properties over time to support a strategy to restore the natural and beneficial functions of historic drainageways and provide for more resilient flood recovery. Buyouts can support various implementation strategies, including stormwater detention, green infrastructure, or daylighting or partial daylighting of pre-development drainageways. This approach requires communicating urban flood risk and limiting built environment engineering strategies such as increasing pipe capacity or elevating levees. Property buyouts may occur before flood events or in the aftermath of a disaster, when citizens are looking for solutions. Having resilient master planning documents that provide large-scale, comprehensive strategies is the first step to reducing losses due to urban flooding over time.

Benefit-cost ratios should be considered over generations rather than only one generation, one mortgage amortization, or one planning horizon. Communities that consider the cost of flood damage over an extended period can weigh the long-term cost to future generations against the potential savings from long-term future planning.

Recommendation 6: Identify Flood Mitigation Funding for Urban Flood Inundation Areas

Implementation costs of solutions to mitigate urban flood hazards are substantial. Mitigation funding must be identified to reduce future flood damage and flood risk. Federal, state, and most importantly, local government organizations have a duty to develop hazard mitigation programs and identify funding for implementing best management practices to reduce future damage due to urban flooding. This effort involves numerous governmental and non-governmental organizations and requires the development of committees to capture ideas on how mitigation funding might be best obtained, combined, and distributed to communities addressing urban flood risk.

SECTION 5: RESOURCES

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ACKNOWLEDGEMENTS

This paper is the result of collaborative effort among ASFPM members. This paper is intended to provide discussion and context for a variety of approaches and programs related to urban flood hazards that have been or are being developed across the United States. The following individuals have supported the development of this paper:

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Dave Carlton, PE CFM D.WRE - Dkcarlton & associates, PLLC | ASFPM Watershed POD Facilitator; content review and editing.

Jerry Murphy, AICP, CFM - University of Florida; content review and editing.

Jeffrey Coop, PE, CFM – Parametrix; content review and editing.

Geoff Brownell, PE, CFM - Associate Vice President - Water Department Manager, Michael Baker International; content review and editing.