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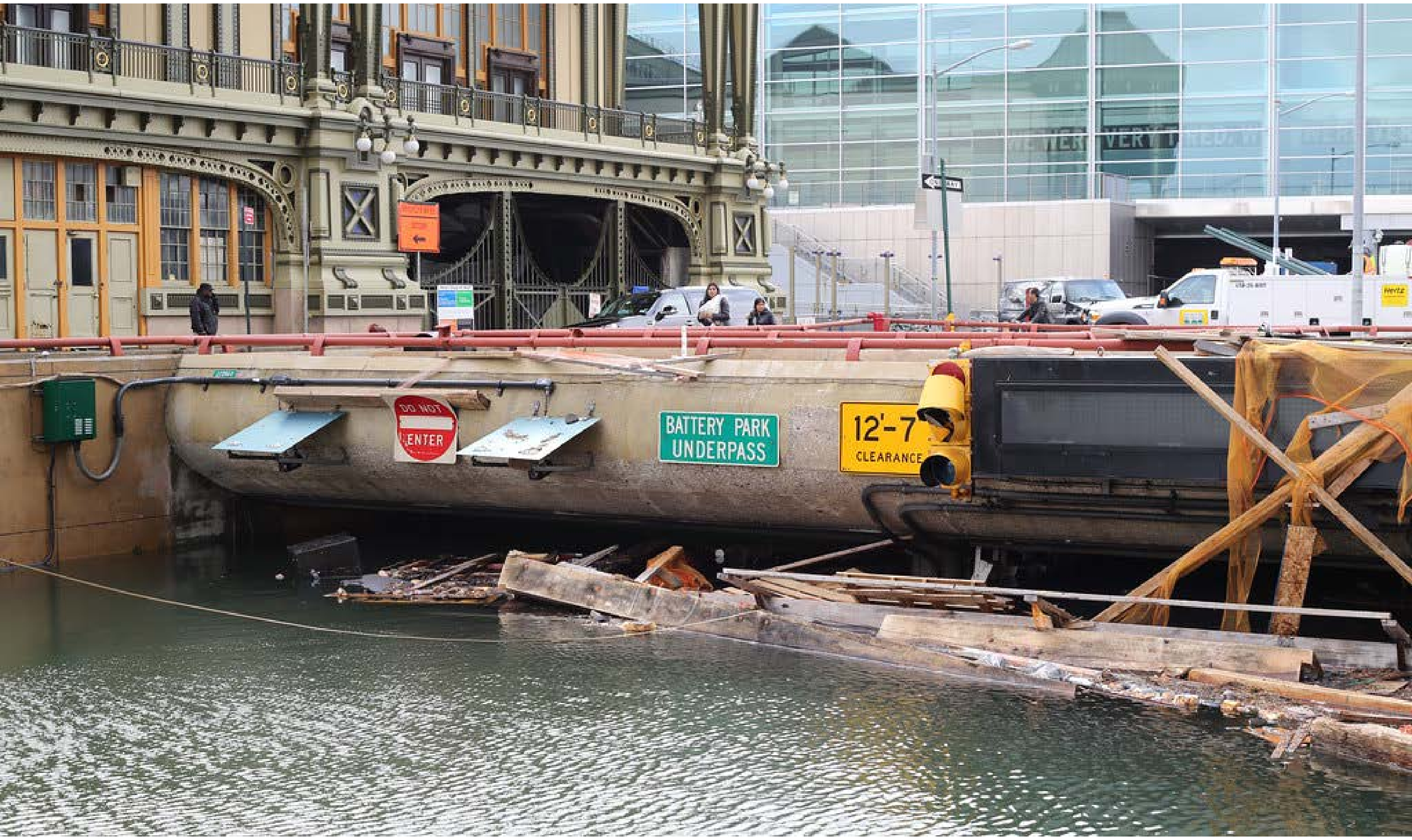

PROJECT NO.

5001

Climate-Resilient Planning for Urban Stormwater and Wastewater Utilities

Workshop Proceedings

Climate-Resilient Planning for Urban Stormwater and Wastewater Utilities: Workshop Proceedings

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THE Water Research FOUNDATION

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Abstract and Benefits

Abstract:

The RAND Corporation, in partnership with the New York City Department of Environmental Protection (NYCDEP) and the Water Utility Climate Alliance (WUCA), convened a workshop in New York City on July 16-17, 2019 to discuss the challenges of climate-resilient planning for urban stormwater and wastewater utilities. This workshop brought together leaders from 15 major metropolitan water utilities in the United States and Canada and other experts to exchange and discuss current practices, lessons learned, and new ideas for developing actionable rainfall projections and incorporating climate-informed stormwater flows into planning processes.

Workshop sessions were organized around themes of regulatory and policy requirements, climate scenarios, and modeling and analyses needed to improve and integrate urban stormwater, wastewater, water quality, and flood mitigation planning. With many cities of all sizes facing similar unresolved challenges in stormwater and wastewater planning and management and in the absence of established practice and guidance, the workshop offered an opportunity to lay the groundwork for future progress on this critical issue, including gaps in the existing best practice, critical research needs, and suggested next steps.

Benefits and Key Take-Aways:

- Contributes to the strengthening information-sharing on climate-resilient planning among U.S. urban stormwater and wastewater utilities.
- Allows some of the nation’s most technically advanced utilities to share their experience with climate data analysis and development of climate projections for planning and design.
- Demonstrates that many utilities are facing increasing threats from longer-duration, high-intensity rainfall events that are causing more frequent flood damage.
- Demonstrates that utilities need to balance attention to compliance with water quality regulations with the increasing risks associated with stormwater and urban flooding.
- Demonstrates that the storm- and wastewater utility sector lacks an established planning and design framework for dealing with climate-driven changes in stormwater flows and urban flooding.
- Demonstrates that global climate models cannot as yet inform how extreme rain events will change in the future and therefore scenario-based and other approaches are needed.
- Demonstrates that workshop participants agreed on the importance of integrated planning, improving methods of handling uncertainties, and exploring new market-based instruments.
- Demonstrates that utilities need to enhance their efforts to communicate with the public about the benefits, costs, and equity of strategies to reduce urban flood risk.

Keywords: Urban stormwater, flood management, resilience, climate, utilities, municipalities, integrated planning, wastewater management.

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Acronyms and Abbreviations

ASFPM	Association of State Floodplain Managers
C40	Non-profit international consortium of cities
CCAP	Philadelphia Water’s Climate Change Adaptation Program
CCRUN	Consortium for Climate Risk in the Urban Northeast (a RISA project)
CMIP5	Coupled Model Intercomparison Project - Phase 5
CSO	Combined sewer overflow
GCM	Global climate model (sometimes also called general circulation model)
IDF	Intensity, duration, and frequency of precipitation events
IPCC	Intergovernmental Panel on Climate Change
LBNL	Lawrence Berkeley National Laboratory
MARISA	Mid-Atlantic Regional Integrated Sciences and Assessments
MWRD	Metropolitan Water Reclamation District of Greater Chicago
NAFSMA	National Association of Flood and Stormwater Management Agencies
NOAA	National Oceanic and Atmospheric Administration
NYC DEP	New York City Department of Environmental Protection
RCP	Representative concentration pathway (from IPCC)
RISA	Regional Integrated Sciences and Assessments program (a NOAA program)
SFHA	Special Flood Hazard Area
SIRP	Stormwater Integrated Resource Planning (Edmonton, Alberta, Canada)
SRF	Clean Water Act State Revolving Fund (an EPA program)
SWMM	Stormwater Management Model (EPA)
USACE	U.S. Army Corps of Engineers
USDN	Urban Sustainability Directors Network
U.S. EPA	United States Environmental Protection Agency
USGCRP	United States Global Change Research Program
WEF	The Water Environment Federation
WRF	The Water Research Foundation
WUCA	Water Utility Climate Alliance

Executive Summary

Intense precipitation events are occurring more frequently in many parts of the United States, according to the Fourth National Climate Assessment, and the frequency of such events is expected to increase as average global temperatures continue to rise. Even in regions where the frequency and intensity are not increasing, damaging and disruptive flooding, reduced drinking water and receiving water quality, and wastewater overflows put lives, property, and environmental assets at risk. In coastal regions, storm surge and sea level are compounding risks that can both cause and exacerbate serious flooding. These extreme events also have exposed important gaps in planning when it comes to effective urban stormwater and wastewater management in a changing climate. Cities are beginning to do more to plan for extreme precipitation, but these efforts have been uneven at best and do not yet reflect a technical consensus on best practices for analysis or planning. There is a strong need for cities to collaborate on developing new approaches to stormwater and wastewater infrastructure planning that account for the compounded uncertainties associated with climate change, future population growth (or decline), land use change, and economic development.

With primary funding from The Water Research Foundation (WRF), the RAND Corporation, in partnership with the New York City Department of Environmental Protection (NYCDEP), the Water Utility Climate Alliance (WUCA), and the Mid-Atlantic Regional Integrated Sciences and Assessments (MARISA) convened the "Climate-Resilient Planning for Urban Stormwater and Wastewater Utilities Workshop" on July 16-17, 2019 at the Newtown Creek Wastewater Resource Recovery Facility in Brooklyn, NY. The workshop brought together representatives from water utilities and urban water departments, universities, non-governmental organizations, the federal government, and local and state governments across the United States, Canada, and Brazil. Participants exchanged and discussed current practices, lessons learned, and new ideas for developing actionable rainfall projections and incorporating climate-informed stormwater flows into planning processes.

Workshop sessions were organized around themes of regulatory and policy requirements, climate scenarios, and modeling and analyses needed to improve and integrate urban stormwater, wastewater, water quality, and flood mitigation planning. With many cities of all sizes facing similar unresolved challenges in stormwater and wastewater planning and management and in the absence of established practice and guidance, the workshop offered an opportunity to lay the groundwork for future progress on this critical issue.

ES.1 Key Take-Aways from the Panel Discussions

ES.1.1 Lack of Regulatory Framework

Water quality regulatory requirements have thus far been driving actions by utilities to integrate the management of wastewater and stormwater. But it has also become apparent that urban stormwater and wastewater management is itself a difficult and nationwide problem and brings to the fore concerns about equity among communities in need of timely responses. Water utilities in cities across the country are struggling to keep up with increasing incidence of extreme rainfall events of increasing intensity and duration. Further, cities and their utilities are working within the constraints of existing water quality regulation and consent orders that can limit their efforts to take a more integrated approach to stormwater management.

At present, however, there is no federal guidance as yet on how to reconcile the statutory and regulatory structure in place to address water quality while also integrating the implementation and management of resilient stormwater solutions. The Water Research Foundation's "Updated User's

Guide for Considering Integrating Wastewater and Stormwater Planning" report[1] (Nemura et al. 2019) provides insight into how the U.S. EPA is better defining integrated planning to allow municipalities the opportunity to better address this challenge. The 2019 Water Infrastructure and Improvement Act (WIIA) (HR 7279), which was passed by Congress in an effort to codify the 2012 Integrated Municipal Stormwater and Wastewater Planning Approach Framework[2] in the Clean Water Act (CWA), provides greater certainty that integrated planning offers a comprehensive path that municipalities can voluntarily take to meet CWA requirements. The process identifies efficiencies from separate wastewater and stormwater programs to best prioritize capital investments and achieve human health and water quality objectives. While this approach may lead to the exploration of many different approaches at the local level, it is unclear whether there is sufficient flexibility or guidance for cities to successfully incorporate non-CWA drivers such as flooding and climate change.

ES.1.2 Near- and Longer-Term Strategies

Some strategies can address growing and persistent flooding and also help control water pollution, such as slowing the entry of stormwater into the drainage network, and increasing the capacities of drainage and collection systems if necessary. Other strategies are primarily aimed at flood management such as: moving excess water away from at-risk areas; securing individual properties in high-risk areas; predicting and managing the movement of stormwater using technologies that allow for real-time response to flooding events; and building up emergency response capabilities throughout the city.

Workshop participants agreed on the value of integrated planning methods despite the administrative and regulatory barriers that exist locally and within the structure of federal environmental law. In fact, integrated planning is already embedded in the federal Clean Water Act, but the role of climate resilience in integrated planning remains unclear. Stormwater management is closely connected to land use and land values, and as such, broader utility strategies to mitigate urban flooding from extreme rainfall events will require on-going communications and engagement with individual communities and other sectors.

ES.1.3 Ongoing Challenge of Developing Climate Projections for Planning and Design

Climate modeling and projections present formidable, but surmountable technical challenges. GCMs cannot provide projections about when, where, how frequently, and at what magnitude these extreme events will occur. Instead, scenario-based and other methods will need to be employed in the foreseeable future to enable urban areas to move forward with their adaptative planning.

Several modeling methods were presented for representing extreme precipitation and urban flooding. Less technical, non-modeling index-based approaches may offer a "walk before you run" strategy for utilities not ready to commit to more sophisticated modeling approaches before those approaches have been more fully developed, tested, and proven effective elsewhere. Further, urban (pluvial) flooding is not typically well characterized outside of coastal or riverine floodplains, in part due to modeling and data limitation.

In the end, there is not as yet a consensus as to what methods are preferred or could be considered best practice at this time. However, there was a consensus on the need for: higher resolution data and models to feed into planning efforts, methods to measure co-benefits of water quality enhancements in

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[1] Nemura et al. (2019) is publicly available via the following link:

https://www.waterrf.org/resource/users-guide-integrated-stormwater-and-wastewater-planning-0.

[2] Additional information on the Integrated Municipal Stormwater and Wastewater Planning Approach Framework can be found here: https://www.epa.gov/npdes/integrated-planning-municipal-stormwater-and-wastewater.

the context of proposed flood mitigation solutions (i.e., green infrastructure), and better communication of uncertainties to communities, regulators, and decision makers.

ES.1.4 Challenges of Post-flooding Response

Finally, cities and their utilities are facing immediate needs. There remain serious difficulties in accessing emergency funds from FEMA following a major flooding event. This is a particular problem for stormwater management measures, which tend to be funded through utility rates based on standard drainage design and water quality needs based on average conditions – both of which do not take extreme events into account.

ES.2 Survey Results

Participants were surveyed before and after the workshop to ascertain their interests and feedback on the effectiveness of the workshop itself. Overall, the majority of respondents considered the workshop to be useful and something they would participate in again. Prior to the workshop, respondents showed interest in a range of topics related to climate-resilient planning, including identifying future climate scenarios and learning new or best management practices. Little change was noticed pre- to post-workshop regarding the factors that respondents considered influential in the effectiveness of stormwater and wastewater management efforts. Suggestions for future workshops included: 1) focusing on topics about the financial or economic aspects of water management, including barriers and opportunities; 2) including more planners and policy makers at all levels (federal through local) as participants; and 3) providing more opportunity for deeper group discussions of solutions to the challenges of climate impacts on stormwater and wastewater management.

ES.3 Future Research Needs

ES.3.1 Integrating the Governance of Stormwater Management, Drainage System Design, and Flood Risk Mitigation

Problem Statement: Agencies attempting to responsibly manage the interdependencies of water quality on proper management of stormwater are caught in a gap in federal programs. As one example, FEMA offers local governments selected opportunities to apply for pre-disaster funds, but FEMA's post-disaster funding approach is not well-aligned with managing stormwater flooding at scale (e.g., watershed management). U.S. Army Corps of Engineers projects pose similar challenges and limitations. Instead, individual stormwater projects are considered separately, and often cannot pass benefit-cost criteria for flood damage reduction in isolation.

Research Need: Better understanding the nature and extent of this problem and developing and analyzing the efficacy of possible policy remedies is a top research priority.

ES.3.2 Establishing a Basis for Levels of Protection from Urban Flooding

Problem Statement: Regulators, agencies, and utilities alike are seeking guidance on how to set appropriate levels of protection – such as clearly defined flood risk frequency or intensity standards – to guide to guide investments in stormwater controls and mitigation measures. This situation stands in stark contrast to the highly regulated environment that drives investments in pollution control, receiving water quality, and drinking water quality.

Research Need: There would be value in research that builds on analytical methods that avoid the "design storm" approach entirely and instead focus on reducing overall vulnerability using decision analytics and decision support methods such as robust decision making.

ES.3.3 Improving Data and Models to Characterize Current and Future Risks

Problem Statement: Utilities rely on extensive data collection networks for water quality and flow monitoring through their watershed and drainage systems. However, they are often operating with inadequate information when managing stormwater flows during intense precipitation events. Data resolution and quality are particularly pressing issues in rainfall measurement. Rain gauges are typically dispersed throughout a city, and simply too geographically dispersed to capture most extreme events for real-time observations, making it difficult to understand and characterize past events or project the impacts of future extreme events. Urban flooding is difficult to estimate and manage in the absence of good data on incoming rainfall, streamflow, and system flows on a time scale of minutes to hours.

Another key challenge is the inadequacy of existing hydrologic and hydraulic modeling tools to simulate urban flooding as part of integrated systems (e.g., combined surface and pipe flow). The state of the art of modeling has not advanced enough to offer a guide on best practice for how to structure models, determine appropriate scales for simulation, and how to integrate or couple surface flow or flood models with well-established water quality models. In general, data and modeling issues place serious limitations on utilities seeking to incorporate climate projections into their planning processes. It also challenges their ability to estimate the potential benefits from stormwater projects intended to mitigate flood impacts. Neither statistical nor dynamical downscaling of global climate model outputs can as yet provide meaningful projections of extreme precipitation at needed spatial or time scales.

Research Need: This is a hard and as yet unsolved problem that requires significant attention of researchers and funders to develop a basis for guidance on how to identify and implement best practices. It is also exacerbated by the data limits noted previously – in particular to support model calibration and validation – as well as confounding land use factors. The inadequacy of current models may ultimately necessitate the development of new integrated modeling tools.

ES.3.4 Estimating Benefits, Co-Benefits, and Return on Investment for Stormwater Projects

Problem Statement: Data and modeling limitations noted previously pose overall challenges to projecting potential benefits or comparing investment options. Even when benefits of reduced flooding can be estimated, there remains the challenge of fully capturing other indirect benefits (co-benefits) that might accrue from some of these stormwater mitigation measures. For example, quantifying the costs associated with flood-induced disruption of business operations, schools, and commerce as well as health impacts on the affected population could be significant in many locations. Co-benefits from green stormwater infrastructure can also be important to local decision making.

Research Need: A key research challenge is the quantification of benefits and co-benefits of investments in mitigating impacts of stormwater and flooding, particularly when many of the actions are highly decentralized.

ES.3.5 Communicating Uncertainty, Risk, and Tradeoffs

Problem Statement: Managing stormwater in the face of climate, regulatory, and funding uncertainties requires utilities to be sophisticated in their communications with the public about risks and the trade-offs entailed across multiple and sometimes competing public objectives.

Research Need: More research guidance is needed on how to incorporate the uncertainties associated with climate projections into planning processes, and for communicating those uncertainties and risks of a changing climate to regulators, residents, public officials, and other stakeholders. Further, stormwater not only poses flood risk, but also risk in the form of missed water quality regulatory standards. It is therefore imperative that the risk-reduction and other benefits of these investments are characterized appropriately to enable decision makers to understand the nature of the trade-offs among competing public objectives.

ES.4 Next Steps

In sum, more work needs to be done to communicate and coordinate approaches among public agencies to address water quality and urban flooding, not only at the local level where the first line of responsibility lies, but also at the federal level where regulatory policy and funding needs to catch up with the growing problems associated with increased incidents of extreme precipitation. To this end, the organizers of this workshop envision three lines of effort to further advance research and best practice:

- Work with a WUCA subcommittee to continue encouraging exploration of new approaches and sharing lessons learned and experience gained among large utilities. Additional partnerships with other organizations will be highly beneficial in bringing additional perspectives to these conversations.
- Share lessons learned from the workshop through additional workshops and other convening opportunities with other water, engineering, and planning organizations. In addition, these convenings should also target small- to mid-sized utilities.
- Identify funding opportunities suitable to addressing the research needs noted in the workshop. The aim here would be to continue to engage current funders, reach out to government and philanthropic funding, and explore new pooled funding models to advance the research agenda.

CHAPTER 1

Introduction

Intense precipitation events are occurring more frequently in many parts of the United States, according to the Fourth National Climate Assessment (USGCRP 2017), and the frequency of such events is expected to increase as average global temperatures continue to rise. In 2019 alone, extreme events such as Tropical Storm Imelda and the July 8th record-breaking cloudburst in downtown Washington, D.C. demonstrated the dramatic flooding that heavy precipitation can bring to urban areas. Pluvial flooding, the primary focus of this proceedings, occurs when lands become saturated or urban drainage systems lack capacity to capture and contain the rainfall. In contrast, fluvial flooding occurs when a river or lake overflows its banks as a consequence of heavy rainfall and runoff in upstream watersheds. For coastal cities, high tide flooding, surge and waves from tropical depressions, and accelerating rates of sea level rise further interact with and exacerbate these heavy rainfall challenges.

Damaging and disruptive flooding, reduced drinking water and receiving water quality, and sewer overflows put lives, property, and environmental assets at risk. These extreme events also have exposed important gaps in planning when it comes to effective urban stormwater and wastewater management in a changing climate. Cities are beginning to do more to plan for extreme precipitation, but these efforts have been uneven at best and do not yet reflect a technical consensus on best practices for analysis or planning. As a result, there is a strong need for cities to collaborate on developing new approaches to stormwater and wastewater infrastructure planning that account for the compounded uncertainties associated with climate change, future population growth (or decline), land use change, and economic development.

In response to this need, the RAND Corporation, in partnership with the New York City Department of Environmental Protection (NYCDEP) and the Water Utility Climate Alliance (WUCA), convened the "Climate-Resilient Planning for Urban Stormwater and Wastewater Utilities Workshop" on July 16-17, 2019 at the Newtown Creek Wastewater Resource Recovery Facility in Brooklyn, NY. The workshop brought together representatives from water utilities and urban water departments, universities, non-governmental organizations, the federal government, and local and state governments across the United States, Canada, and Brazil. The majority of attendees were affiliated with water utilities from large cities within the United States.

This two-day workshop was made possible by funding from The Water Research Foundation (WRF). In-kind support for this workshop came from multiple sources. The New York City Department of Environmental Protection (NYCDEP) provided leadership and staff time for workshop preparation and execution, the workshop venue, and logistical support. The National Oceanic and Atmospheric Administration (NOAA)-funded Mid-Atlantic Regional Integrated Sciences and Assessment (MARISA) program provided the resources for the design and execution of the pre- and post-workshop surveys and preparation of the workshop summary. In addition, multiple WUCA-affiliated utilities provided support for their staff's time and travel costs to attend the workshop.

1.1 Workshop Objectives

The objectives were to advance the state of the science and engineering and provide value for utilities by:

- Identifying new methods and best practices for managing urban stormwater and wastewater while considering climate change and future uncertainties.
- Sharing ideas to inform more robust urban stormwater and wastewater infrastructure strategies to meet future needs.
- Building capacity to adopt and implement new integrated planning methods.

In the near term, those who participated in the workshop had the opportunity to learn about best practices and share their experiences with stormwater planning under uncertainty, while helping to lay the groundwork for a new community of practice around robust urban stormwater and wastewater planning patterned after WUCA. The WUCA collaborative model provides a mechanism for cities to work with expert partners to build and apply cutting-edge methods for stormwater and wastewater management evaluation, including new estimates of urban flood risk under present and future conditions. Participants from utilities can draw on this expertise to help update and develop new stormwater and wastewater infrastructure investment plans.

The longer-term vision is that cities will reap the benefits of improved stormwater and wastewater management through increased resilience and reduced vulnerability to damage and disruption from extreme precipitation events. To this end, workshop organizers envision that a WUCA-like consortium on climate-resilient planning methods could help transform how cities adaptively plan, invest, and manage stormwater and wastewater systems. Along the way, cities and participating utilities will need to build their internal capacity to apply new methods and develop robust investment plans, and update and improve these plans adaptively as conditions and planning assumptions change.

The workshop explored four themes: 1) the challenges of integrated water planning within the current regulatory context, 2) climate resilience and scenario inputs, 3) the continuum of modeling tools and the challenges of model integration, and 4) synthesis of workshop insights and development of next steps. These themes are described in detail in Chapters 2 and 3.

1.2 Description and Roles of Workshop Partners

The workshop was the product of a collaboration begun more than two years ago between RAND and NYC DEP, motivated by the emergent challenges of stormwater planning and management in a changing climate, and inspired by the formation and growing salience of WUCA. In addition to its considerable subject matter expertise, WRF's decision to support the workshop in November 2018 provided the means of bringing together thought leaders from the stormwater and wastewater management sector to share experiences and consider new ideas. As such, the roles of workshop partners were closely intertwined and coordinated.

1.2.1 RAND Corporation

RAND is a non-profit, non-partisan policy research organization with a long history of conducting research on policy and planning challenges related to water and global climate change, including integrated coastal and inland water planning (RAND 2019a, RAND 2019b). RAND's work in coastal Louisiana (Groves et al. 2014); South Florida (Groves et al. 2018); Jamaica Bay, New York City (Fischbach et al. 2018); and Pittsburgh (Fischbach et al. 2017), among other places, informed the agenda of the workshop around the importance of appropriately structuring climate-relevant scenarios, integrating simulation models of hydrologic and other processes, and engaging early and often with decision makers and stakeholders. *Robust Stormwater Management in the Pittsburgh Region: A Pilot Study* (Fischbach et al. 2017) is particularly relevant to the content of this workshop.

RAND had lead responsibilities for organizing the workshop, working closing with NYC DEP at each step in the workshop planning process to shape the agenda, refine the participant invitation list, and arrange for workshop logistics. RAND also developed and administered the pre- and post-workshop surveys, and took the lead in drafting these workshop proceedings.

1.2.2 New York City Department of Environmental Protection

NYC DEP is the water and wastewater utility for New York City. Its mission is to "enrich the environment and protect public health for all New Yorkers by providing high quality drinking water, managing wastewater and stormwater, and reducing air, noise, and hazardous materials pollution" (NYC DEP 2019). New York City has pioneered the development and communication of climate-relevant information for local and regional decision makers. Throughout the workshop planning period, NYC DEP worked in close partnership with the RAND team in shaping the focus of the workshop, identifying speakers and participants for the workshop, and facilitating logistical arrangements including the arrangement to hold the workshop at the Newtown Creek Resource Recovery facility in Greenpoint, Brooklyn.

1.2.3 The Water Utility Climate Alliance (WUCA)

WUCA, whose membership includes 12 of the nation's largest water providers, was established to "provide leadership and collaboration on climate change issues affecting the country's water agencies" (WUCA 2019). WUCA provided travel support for WUCA members to attend the workshop. WUCA staff were involved in developing key questions and research needs common to stormwater and wastewater infrastructure that informed the workshop agenda. Drawing from the workshop's findings, a WUCA subcommittee will develop and refine a list of research needs that relate to precipitation, and stormwater/wastewater infrastructure design, planning, and analysis. This will involve exploring and identifying the relevant questions that are common across the WUCA network involving intense precipitation events and its effects on wastewater and stormwater.

1.2.4 The Water Research Foundation (WRF)

WRF provided the essential support that made the workshop possible. A summary of WRF's mission and activities can be found opposite the inside front cover of this proceedings. WRF staff provided periodic guidance to the workshop team primarily with regard to the shaping of the participant list, ensuring broader geographic representation among the utilities.

1.2.5 Mid-Atlantic Regional Integrated Sciences and Assessments (MARISA)

MARISA is one of 11 NOAA-funded regional collaborative climate information and dissemination efforts in the United States in the Regional Integrated Sciences and Assessments (RISA) program (NOAA 2018). MARISA's mission is to help Mid-Atlantic communities become more resilient to a changing climate through improved data, place-based decision support, and public engagement. MARISA's geographic scope includes the Chesapeake Bay watershed and the states within the boundaries of the watershed. Bringing actionable climate information to communities facing stormwater challenges is one of MARISA's principal areas of focus. MARISA supported the pre and post-workshop surveys and the drafting, editing, and final preparation of this proceedings.

1.3 Purpose of the Conference Proceedings

The purpose of this proceedings is to summarize and synthesize the presentations and discussions of the four workshop panels and offer observations and guiding principles on the practice on urban stormwater and wastewater planning. The document is organized as follows. Chapter 2 presents the methodology used in organizing and structuring the content of the workshop, selecting participants and speakers, and developing a pre- and post-workshop survey to guide workshop planning and gather feedback from participants on the value of the workshop experience. Chapter 3 summarizes the content and primary take-aways from each of the panel discussions, and Chapter 4 synthesizes the feedback from participants during the break-out session at the end of the workshop. Chapter 5 describes the main findings from the pre- and post-workshop surveys. Finally, Chapter 6 presents conclusions and directions for future research.

CHAPTER 2

Methodology

This chapter describes the methods used in developing the workshop's overall structure, themes and guiding questions, selection of speakers and participants, and development of a pre- and post-workshop survey.

2.1 Workshop Themes and Structure

The workshop was structured around four panel discussions and a final session of four breakout groups and their synthesis of key messages emerging from the workshop:

- Plenary panel: Stage-setting.
- Theme 1 panel: integrated infrastructure planning and the current regulatory context.
- Theme 2 panel: Climate resilience and scenario inputs.
- Theme 3 panel: Continuum of modeling tools and model integration.
- Theme 4 breakout groups: policy levers and implementation.

Each moderated panel included 10-minute presentations by each of four panelists followed by 30 minutes for discussion and questions. The final session of the workshop was structured around four breakout groups that reflected on the content of the workshop and considered priority topics for follow-up. A detailed agenda can be found in Appendix A.

The choice of themes and their ordering was structured around a narrative of moving from the big picture of challenges and needs to the technical details of climate scenarios and integrated modeling. The first day's presentations were intended to build a common understanding of the broader context of the threats, operational challenges, and planning needs for climate-resilient integrated stormwater and wastewater management. The stage-setting panel was followed by a panel discussion later in the afternoon focused on the current state of integrated infrastructure planning and the regulatory context within which planning and priority-setting is done. On the second day of the workshop, discussions moved to the details of appropriately structuring climate scenarios and utilizing climate data in the context of integrated planning-level simulation modeling.[3] The workshop concluded on the afternoon of the second day by assigning participants to break-out groups, with each group broadly representing participating utilities, other experts, and the workshop planning team. In the smaller group setting, participants shared their thoughts about key messages emerging from the workshop and then ordered their view of top priorities for near- and longer-term action. The workshop concluded with breakout group leaders sharing their group's thoughts with the others.

2.2 Speakers and Other Participants

The workshop was an invitation-only event, and was limited to 40 to 50 total participants to encourage active engagement and discussion. The workshop targeted thought leaders in major urban U.S. stormwater and wastewater utilities who are proactively working to incorporate climate change considerations into their planning processes and seeking better understanding of analytical methods being explored by other utilities. Invitations were sent to senior technical and program leads from

[3] In this report, the term "climate data" includes not only projections from the output from global climate models (GCMs) but also historical storm events or paleoclimate and more recent observed phenomena indicative of past climate regimes.

selected water utilities and agencies responsible for stormwater and wastewater planning, representatives from WUCA, WRF, NOAA, and non-profit organizations in a position to leverage their own networks of practitioners.

Speakers were selected based on several criteria: their expertise and experience in integrated water management, climate science, and regional planning; their knowledge of methods and their application in the field; and their representation of different regional and geographic settings. Speakers included subject matter experts not associated directly with a water utility or municipal agency. However, participation from the academic, nonprofit and consulting sectors was limited to maintain the focus of discussions on participating cities and utilities.

Ultimately, 48 participants attended for at least one day. A list of participants' names and affiliations can be found in Appendix B.1. The participants came from 15 urban areas across the United States, Canada, and Brazil shown in Figure 2-1. A regional breakdown of workshop participants is included in Table 2-1.

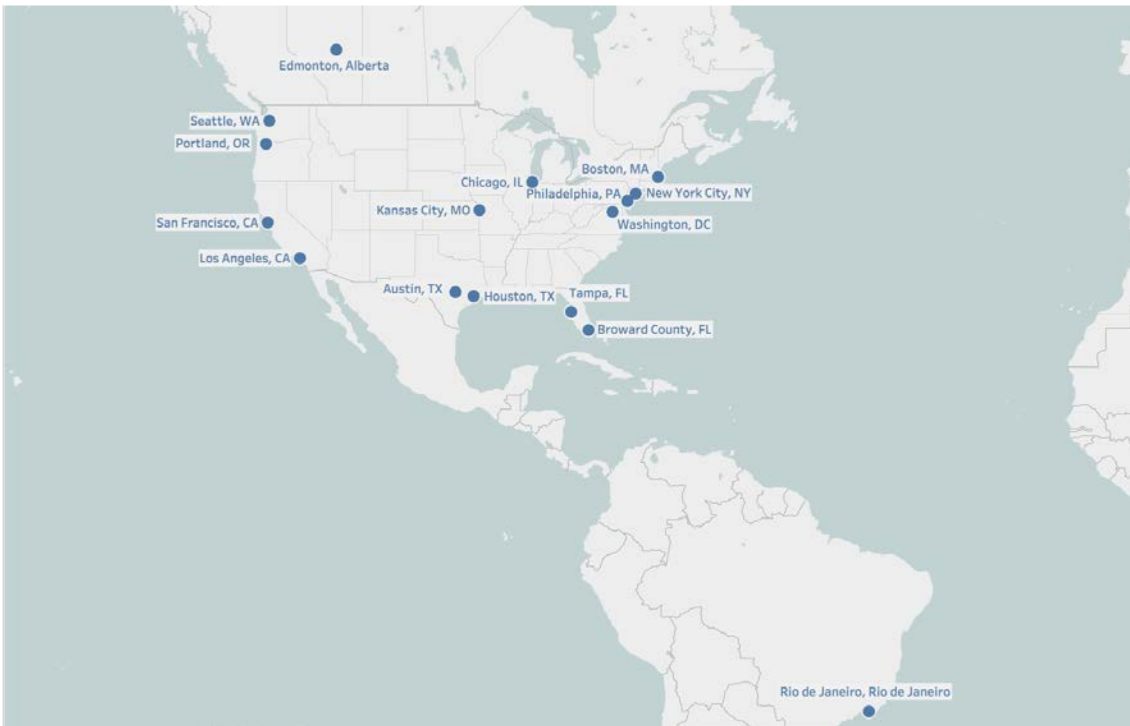

Figure 2-1. Urban Areas Represented at the Workshop.

Table 2-1. Regional Distribution of Workshop Participants.

U.S. Region	Number of Participants
Northeast* (NY, MA)	18
Mid-Atlantic* (PA, VA, MD, DC)	13
West (CA, WA, OR)	7
Southwest (TX)	3
Midwest (MO, IL)	3
Southeast (FL)	2
International Representation	
Brazil	1
Canada	1

** Note: Participants from the Northeast and Mid-Atlantic regions included the RAND team and representatives of NOAA and WRF.*

2.3 Synthesis of Workshop Discussions

The RAND/MARISA team took extensive typed and hand-written notes throughout the workshop. No recordings were made of the proceedings to further encourage open and candid conversation. These notes were combined and edited after the workshop and shared with the speakers for their review and editing. They provided the support for the summaries and findings in these proceedings.

2.4 Pre- and Post-Workshop Survey

Participants were surveyed before and after the workshop for several purposes. For the pre-workshop survey, the RAND-NYC DEP team was interested in eliciting participants' understanding of workshop objectives and their expectations about the knowledge they hoped to gain from their participation. The survey would also indicate the range of knowledge among workshop participants about urban stormwater and wastewater management. The post-workshop survey sought feedback from participants on the value they derived from each of the panels and from the workshop as a whole. The paper-based survey instruments are included in Appendix C.

CHAPTER 3

Summary of Panel Discussions and Key Take-Aways

This chapter synthesizes each of the panel discussions and breakout session, and concludes with a section synthesizing the key messages that emerged from each. Speakers' biographies are included in Appendix B. Information about the composition of the panels and the guiding questions that guided each session are included in Appendix C.

3.1 Plenary Panel: Setting the Stage

Moderator: Pedro Ribiero, Project Officer, Adaptation Initiative, C40 Cities Climate Leadership Group.

The plenary panel set the stage for the entire workshop, providing an overview of the challenges of managing extreme precipitation and urban flooding, the current state of the art of urban stormwater and wastewater planning, and the scientific and engineering questions surrounding the incorporation of climate projections and other uncertainties into the planning process.

Dr. Gerald Galloway, from the University of Maryland, provided a nation-wide perspective on the scope, consequences, and challenges associated with urban flooding, highlighting the key findings of a November 2018 report entitled *The Growing Threat of Urban Flooding: A National Challenges* (University of Maryland 2018). A survey of over 700 stormwater and floodplain management practitioners found that 85% of respondents had experienced urban flooding, and 85% had experienced flooding outside of the Special Flood Hazard Area (SFHA). Additionally, the survey found that the triggers of urban flooding are varied and difficult to address. These triggers include increasing episodes of intense rainfall events; aging, inadequate, and poorly maintained drainage infrastructure; and increased development with more impervious surfaces. The economic and social costs associated with urban flooding include damages to infrastructure, high impacts on small businesses, affordability of insurance, and loss of property values. Urban flooding has a disproportionately large effect on those who are least equipped to deal with it, due to the prevalence of poor drainage and flooding in vulnerable, lower-income communities. The major challenges associated with urban flooding are: climate change, population growth, lack of resources, priority setting, and governance. Finally, Dr. Galloway noted that urban flooding is a growing nation-wide problem, whose extent, consequences, and possible solutions are not well understood.

Claudio Ternieden, JD, from the Water Environment Federation, spoke about the regulatory context for stormwater and wastewater planning, particularly about regulatory issues under the Clean Water Act (CWA; 33 U.S.C. §1251 et seq. 1972). Many cities are under federal consent decrees to comply with the CWA, and have been working to fulfill their long-term control plans to either remain or come into compliance. Many of these cities, despite spending billions of dollars implementing these plans, are still falling short of the required water quality standards. Cities are struggling to figure out how to proceed once their consent decrees and existing long-term plans end. One approach is for them to engage in integrated water planning, an approach recently formalized in the CWA. Mr. Ternieden also noted that the U.S. Environmental Protection Agency's (EPA) measures for determining affordability would benefit from updating. The Water Environment Federation (WEF) is conducting studies and using their findings to encourage Congress and the EPA to consider increasing federal contributions to the Clean Water State Revolving Fund (SRF) as an investment in the future.

Susan Ancel, from EPCOR, spoke about their approach to stormwater management, particularly their Stormwater Integrated Resource Planning (SIRP) effort. The SIRP took the approach of segmenting the city of Edmonton into about 1400 sub-basins, based on the existing pipe network and surface topography. Each sub-basin was ranked by health and safety, environment, social, and financial risk levels, under conditions ranging from a 20-year storm (5% chance of occurring annually) to a 200-year storm (0.5% change of occurring annually). The resulting risk maps, which can be updated as more data become available, show the risk to sub-basins over a range of storm intensities. The long-term goal is to reduce all flooding risk, and use a risk prioritization approach to determine where to focus mitigation efforts. SIRP has developed five major themes for flood mitigation: 1) slow the entry of stormwater into the drainage network, 2) move excess water away from at-risk areas, 3) secure individual properties in high-risk areas, 4) predict and manage the movement of stormwater using technologies that allow for real-time response to flooding events, and 5) build up emergency response capabilities throughout the city. Additionally, they found that green infrastructure contributes to the mitigation of impacts from drought, heat waves, and urban flooding, and is a key component of the SIRP. EPCOR reports and presentations on the SIRP to the City Council's Utility Committee are all publicly available on the City of Edmonton's website (links are provided in the references).

Yvonne Forrest, the Director of Houston Water, spoke about Houston's experiences of flooding both during and after Hurricane Harvey. Hurricane Harvey exposed Houston's vulnerabilities. The city is still trying to recover, and Houston Water is still doing functional asset tests almost two years later. Harvey also highlighted issues is accessing emergency funds; they still have not received any funds from FEMA. As a result, Houston Water has learned that it cannot rely on FEMA to cover the costs of immediate repairs to facilities in a timely way and provide the funds needed for recovery. Ms. Forrest also highlighted weaknesses in the National Weather Services' (NWS) predictions. NWS did not predict how much rain Houston was going to get until it was already happening, which limited the city's ability to prepare.

In summary, the speakers talked about integrated stormwater and wastewater management from a range of perspectives, but all agreed that meeting current regulators requirements and mitigating urban flooding from an increasing number of extreme precipitation events is an enormous problem that affects cities of all sizes throughout the country and will continue to be challenging to address under current regulatory and governance conditions. More work needs to be done to communicate and coordinate approaches among public agencies to address water quality and urban flooding, not only at the local level where the first line of responsibility lies, but also at the federal level where regulatory policy and funding needs to catch up with the growing problems associated with increased incidents of extreme precipitation.

3.2 Theme 1 Panel: Integrated Infrastructure Planning and the Current Regulatory Context

Moderator: Alan Cohn, Managing Director for Integrated Water Management, NYC DEP.

This panel focused on the range of operational and planning objectives that stormwater and wastewater utilities are trying to achieve now and in the future. Utilities in this sector must work towards a range of different objectives at once; and policy decisions or investments to help achieve one objective may help or hinder progress towards others.

Dr. Pinar Balci, from NYC DEP, spoke about New York City's efforts to meet combined sewer overflow (CSO) mitigation targets while dealing with increasing rainfall. New York City has already spent $4.2 billion to get a reduction of 5.6 billion gallons a year in CSOs. Future efforts will cost over $5 billion to reduce an additional 3.2 billion gallons of CSOs. The diminishing returns are a consequence of already having completed the most cost-effective projects, and now having to work harder to get flow reductions. Dr. Balci noted that New York City is working on how CSO investments can be better coordinated with balancing other competing needs such as state-of-good-repair, resiliency, drainage, and energy projects, while sustaining affordability. One example of this kind of thinking is the New York City Green Infrastructure Program. As part of this program, they have installed over 4300 green infrastructure assets and managed over 465 greened acres (as of 2017). The program has $1 billion budgeted over the next ten years. Additional efforts include building infiltration basins, working on getting legislation passed to expand stormwater construction requirements, and using ecological/biological treatment systems (i.e., wetlands, green infrastructure, muscles). Questions from workshop participants highlighted the issue of maintenance costs for green infrastructure. NYC DEP currently handles the maintenance for over 4000 assets, which requires a team of 50 to 60 people. As the number of assets increases, so will the number of people needed to handle maintenance.

Figure 3-1. Implications of Climate Change: More CSOs and Flooding.
Residual flooding after Superstorm Sandy (left); Wet Weather Discharge Point (right)
Source: New York City Department of Environmental Protection.

Brent Robinson, from Seattle Public Utilities, presented Seattle's approach to dealing with CSOs. The state of Washington's standards for CSOs are to have no more than one event per year, on average, for the preceding 20-year period. There is a federal consent decree to achieve this standard across all basins by 2030. All of the modeling that was done for Seattle's long-term control plans was done in 2010, using historical data. Then, in five years, the number of gallons of control volume increased by 350% as a consequence of changes in rainfall intensity, thus rendering their long-term control plan completely obsolete. It is clear that CSOs will never completely go away and basins will fall out of compliance over time. The large uncertainties from climate change and other factors make it difficult to use a single approach or milestone for planning in which a control volume is set and system designed at least cost. Seattle is changing its approach to stormwater management and working to engage state and federal regulatory authorities early to discuss uncertainties and their nexus with milestones. The city is also working to build a broader infrastructure vision that allows for adaptive management to more effectively contend with major uncertainties. This will allow them to embed their CSO needs into a larger planning framework, and therefore get more value out of their CSO investments, moving them from "least cost" to "highest value" planning.

Joseph Kratzer, from the Metropolitan Water Reclamation District of Greater Chicago, spoke about their approach to integrated stormwater planning. They developed a Green Infrastructure Plan in 2015, and a Stormwater Master Planning program in 2018. They knew that they needed to take an innovative approach, given the wide variation in how communities handled their planning and infrastructure. The Metropolitan Water Reclamation District of Greater Chicago drew on previous studies that identified locations where flooding was occurring using geographic information system (GIS) data and other information from public reports. Going forward in their Master Plan process, the District is collecting information from all communities. The end goal is to create plans that communities can embrace as their own. The District is focused on reducing flooding of residences and businesses and aligning stormwater improvements to promote both economic growth and resilience. If flooding problems can be mitigated in communities, they can then grow their economic base and be better equipped to deal with flooding on their own.

Marc Cammarata, from Philadelphia Water, discussed their integrated, long-term, and watershed-wide planning approach which is aligned to meet regulatory requirements to protect the long-term health of the community and environment. In 2011, Philadelphia Water started the Green City, Clean Waters program to meet their long-term control plan, using green design, and green stormwater infrastructure. All told, they have greened over 1,845 acres city-wide and funded over 650 projects. Additionally, Philadelphia Water is in the process of implementing a Drinking Water Master Plan that includes 400 individual projects, 10 of them being key projects, at an estimated cost of $2.5 billion. Cammarata also spoke about their concerns with having to deal with nutrient management and saltwater intrusion in their water supplies, particularly in a changing climate that will increase the amount of precipitation in Philadelphia while also increasing sea levels, salinity in the Delaware estuary, and surface temperature. In light of these concerns, Philadelphia Water needs additional data to feed into their modeling tools to provide the technical basis for integrated planning.

Figure 3-2. Integrated Long-Term Planning Approach.
Source: Philadelphia Water Department

In summary, panelists highlighted the relatively rapid changes underway in their respective jurisdictions as they each try to cope with the increased intensity, and in some cases frequency, of extreme precipitation events and consequent CSOs and flooding. Water quality is a key driver of action. New York, Philadelphia, Seattle, and Chicago are each undertaking strategies to retain storm water temporarily through the aggressive development of small-scale green infrastructure. These efforts need to be closely coordinated and managed within the context of water quality and other regulatory requirements. Stormwater management is closely connected to land use and land values, and as such, broader utility strategies to mitigate urban flooding from extreme rainfall events will require on-going communications and engagement with individual communities. While each of the cities is working within the constraints of existing regulation and consent orders, an integrated approach to stormwater management can still be achieved within those constraints.

3.3 Theme 2 Panel: Climate Resilience and Scenario Inputs

Moderator: Adam Parris, Mayor's Office of Resiliency, New York City.

The Theme 2 Panel focused on how historical and climate-projected rainfall estimates are being used to inform planning and decision making. Panelists discussed: the state-of-the-art regarding how hydrologic uncertainties are being represented and applied; approaches to understanding and characterizing extreme precipitation given a changing climate; and key open questions utilities still have to establish best practices for incorporating climate and hydrology uncertainty into near- and long-term plans.

James Rufo Hill, from Seattle Public Utilities, discussed how the number of extreme precipitation events Seattle has experienced has changed significantly since 2003. An extreme event being one with a 25-year or greater recurrence probability. Prior to 2003, they had an extreme event about once per decade, but in the stretch from 2003 to 2015, they had an extreme event about every one to three years. These findings imply that Seattle's Intensity-Duration-Frequency (IDF) curves were no longer valid. They worked to extend their rainfall records from 1977 until today. Analyzing this period of record showed that rainfall has, in fact, become more intense, particularly in the form of six- to 24-hour duration events. In addition to updating their historical records, they also began considering how rainfall will change in the future. To do this, they used Coupled Model Intercomparison Project Phase 5 (CMIP5) data and ran an ensemble of models to update their IDF curves (Taylor et al. 2012). These modeling efforts are being used to inform integrated system planning.

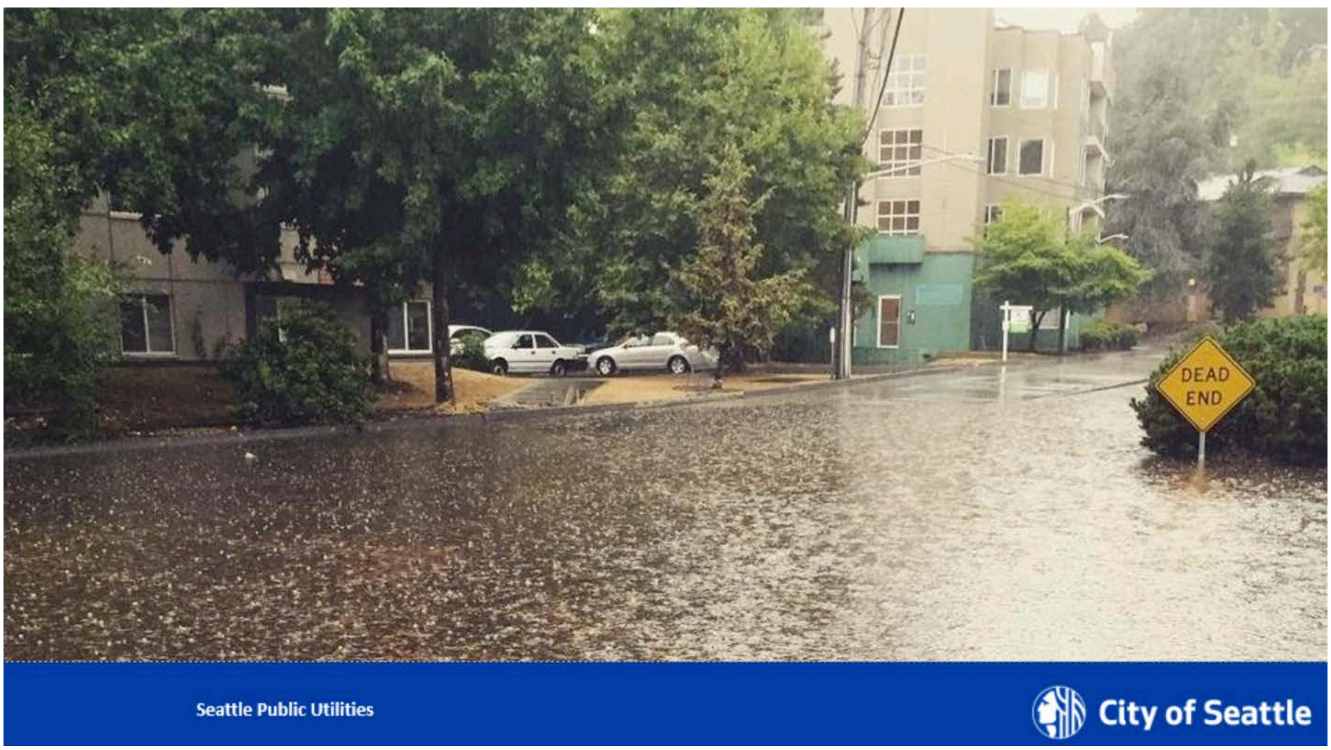

Figure 3-3. Flooding in Seattle.
Source: James Rufo Hill.

Julia Rockwell, from Philadelphia Water, spoke about their Climate Change Adaptation Program (CCAP), which was established in 2014. The goal of the program is to reduce the risk and associated expenses that Philadelphia Water will face from the impacts of climate change by identifying and implementing effective and feasible adaptation strategies. The City's Office of Sustainability and their consultant used statistically downscaled global climate model (GCM) output to develop their first climate change adaptation plan in 2015. When the Philadelphia Water Department (PWD) CCAP analyzed this output, they found that the downscaled GCMs had inadequate temporal and spatial resolution for urban stormwater applications. Additionally, the GCMs did not accurately simulate local rainfall patterns. To produce actionable science, CCAP developed a method (time series adjustment method) that accounts for varying increases in precipitation depending on storm size and season. They also developed a stochastic rainfall generator to explore variability for current and future conditions. By combining results from the time series adjustment method and the stochastic rainfall generator, CCAP was able to create updated and future IDF curves using observed data and rainfall projections based on the Intergovernmental Panel on Climate Changes' emissions scenarios (Maimone et al. 2019). Their next step is to incorporate these analyses into Philadelphia Water's planning and design processes and to inform other city agencies and partners about their work.

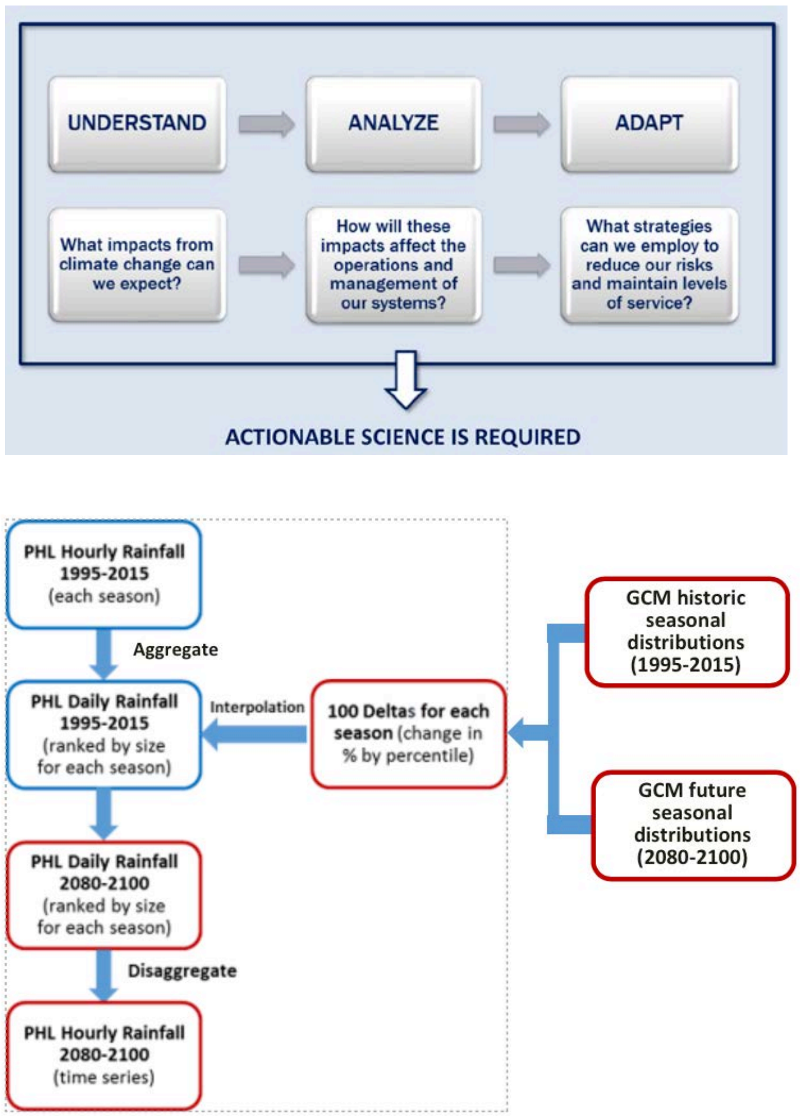

Figure 3-4. Philadelphia Water Department's Climate Change Adaptation Program Including One Approach to Creating Actionable Precipitation Projections.

Source: Julia Rockwell.

Anna Roche, from San Francisco Public Utilities, provided an overview of the San Francisco Public Utility Commission (SFPUC). The PUC is leading the effort to look at the latest climate science and pursue other research opportunities, with a particular focus on understanding future storm intensity/extreme precipitation due to climate change. They are looking for modeling to help point to strategies for dealing with future flooding scenarios. They are currently working with Lawrence Berkeley National Laboratory (LBNL) on modeling because LBNL has the computational capabilities that can bring the resolution of the climate models down to 3 to 4 kms (or about 1 mile)[4]; thus far, they have simulated four historic storms. LBNL will simulate outputs for different climate projections (RCP4.5 and RCP8.5) to determine how different these four storms would look in a warmer climate. This methodology is transferrable, and the PUC would like to collaborate with others, although access to supercomputing resources is a constraint. The PUC also anticipates pulling together a Technical Advisory Committee that could speak to the uncertainty related to these models and their outputs.

Dr. Radley Horton of Columbia University and the Consortium for Climate Risk in the Urban Northeast (CCRUN) spoke about the limitations of GCMs' ability to project changes extreme precipitation. A roughly 55% increase in the amount of rain that falls on the wettest day in a year has been observed in the Northeast United States. Nothing like this shows up in the models. Understanding of the physics suggests that climate models cannot as yet inform understanding of how extreme rain events will change. As the atmosphere gets wetter, there could be big changes in the wettest hours that GCMs cannot simulate. In response, there are new paradigms worth exploring, such as scenario-based approaches. Reliance on GCMs is warranted for the things these models do well (e.g., ocean thermal expansion), but there is a need to come up with other ways to address the things that GCMs do not do well (e.g., change in extreme rainfall frequency at decision-relevant temporal and spatial resolution).

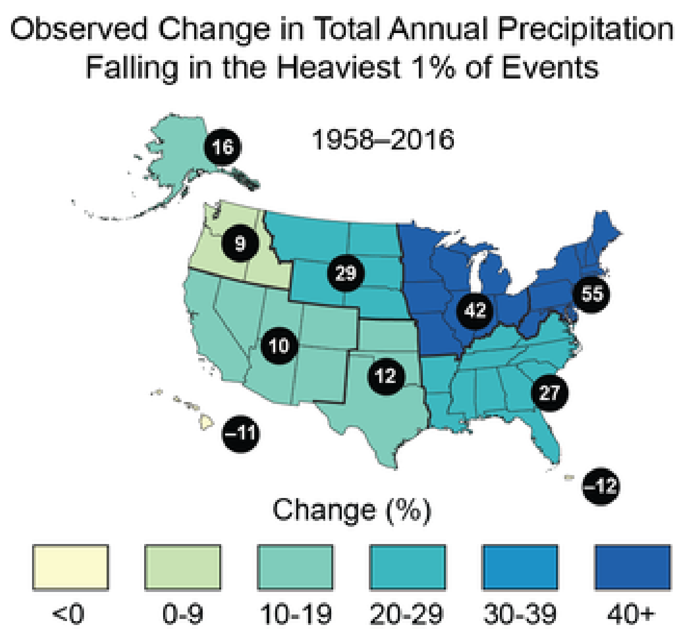

Figure 3-5. Percentage Change in 99th Percentile Precipitation in the United States, 1958-2016. Source: National Climate Assessment 4, Chapter 2, Figure 2.6.

[4] LBNL has the fifth most powerful computer in the world. Each simulation will use about 1000 processors and the project will use over two million supercomputing hours.

Panelists each touched on the relative strengths and weaknesses of their respective technical approaches to working with climate projections. With all of these methods, however, the challenge remains of accurately conveying uncertainty of the findings with respect to extreme rainfall events. As noted by Dr. Horton, reliance on GCMs is warranted for the projections they can do reasonably well, but scenario-based and other methods will be needed to address extreme precipitation which falls outside the skill of GCMs to project. The discussion also drew out other issues with the application of climate projections including their coarse temporal and spatial resolution and the costs of high-speed computing. Caution is therefore warranted in applying these emerging analytical methods at this time to project future extreme precipitation conditions.

3.4 Theme 3 Panel: Continuum of Modeling Tools and Model Integration

Moderator: Jordan Fischbach, Senior Policy Researcher at the RAND Corporation.

The Theme 3 Panel provided an introduction to hydrologic and hydraulic (H&H) modeling, and new and innovative approaches to apply simulation model, in isolation or combination, to support climate-resilient storm- and wastewater planning. Panelists discussed a wide range of approaches from "rule of thumb" guidelines to high-resolution and/or integrated simulation modeling suites.

Dr. Franco Montalto of Drexel University provided an overview of new approaches to developing and applying simulation models, in isolation or combination, to support climate-resilient storm and wastewater planning. Hydrologic models attempt to represent surface flow processes (rainfall, infiltration, evaporation, runoff generation). Hydraulic models use the governing equations of fluid dynamics and mechanical behavior of water to represent flow through drains, inlets, pipes, and over weirs. Together, these two types of models are referred to as "H&H" models. The common industry standard H&H model is EPA's Stormwater Management Model (SWMM; Rossman 2015) and proprietary derivatives of it. There are at least four challenges in using existing H&H models for simulation of extreme precipitation. Appropriate extreme conditions need to be selected for the model. This requires many data and assumptions. Various techniques exist for simulating extreme precipitation, but currently there is no consensus on which technique is best. As extreme events become more uncertain, it will be more difficult to assume that a model validated with one set of observations will be valid for other applications. A third challenge relates to the spatial resolution of structures within the hydraulic models that may have the effect of "losing water" and therefore inappropriately accounting for inflows and outflows. Finally, the current hydraulic models cannot adequately capture wave and other overland flow dynamics.

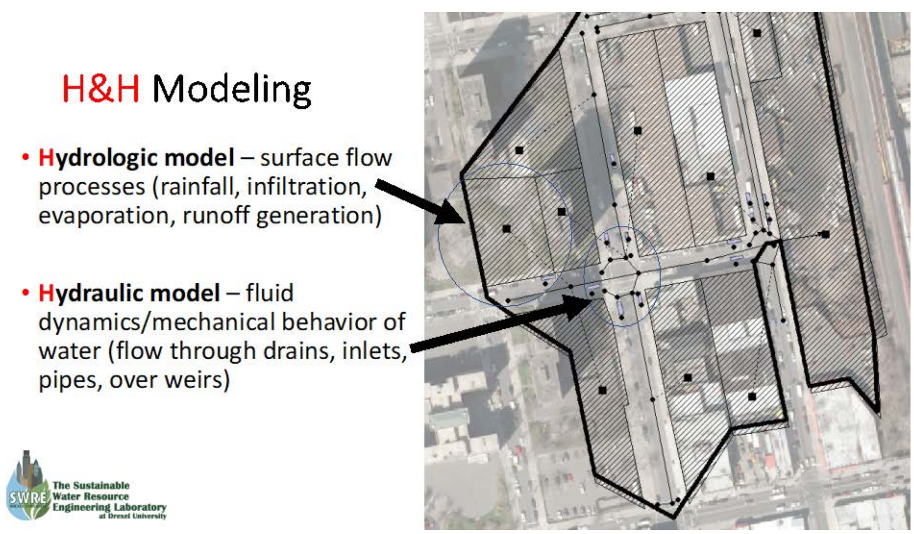

Figure 3-6. Distinction Between Hydrologic and Hydraulic Models.
Source: Franco Montalto.

Dr. Mark Maimone of CDM Smith spoke about the different methods used for H&H model integration. Full model integration refers to bringing rainfall/runoff, urban drainage system, streamflow, and groundwater into one model. There are potential advantages to this approach to modeling, particularly that it better reflects the system and can identify unexpected interactions between system elements. However, integrated models are difficult to develop, calibrate, and validate. Additionally, run times can be long and expensive. An alternative approach, and the one used by Philadelphia, is called “loose coupling.” In this approach, models are developed and calibrated separately for each system element. The output of one model is used as input to another model with data transfer and updating happening external to the models. This approach has the advantage of greater ease in calibrating the individual models. However, the approach requires multiple models and modeling specialists, and can, therefore, be costly. Cities need to use models to better understand their urban water cycle. Multiple models generally are needed to answer the questions of both city managers as well as the regulatory agencies. If more than one model is needed, then thought must be given to how the models will interact. Each city will need to decide how to approach this challenge. Loose coupling is currently the more common approach.

Dr. Carolina Coelho Maran, from Broward County, spoke about their experiences with integrated modeling. In 2019, Broward’s integrated water plan was updated and now constitutes the foundation of the county’s efforts. This plan marks the first time that stormwater and flood risk have been brought into Broward County’s integrated planning framework, which also incorporates climate adaptation needs. There are two major modeling efforts in place. The first uses a MIKE model (Hammond 2012; Domingo 2010) to evaluate water management options in the early 2000s. The second uses the USGS MODFLOW package (Langevin 2018) to understand urban hydrology for the purpose of identifying wet and dry retention areas and ensuring proper functioning of offsite storage. These robust modeling tools are being developed to guide water management strategies, balance water supply demands and flood vulnerabilities, and support future infrastructure investments and long-term sustainability. Broward has also been developing a future rainfall dataset.

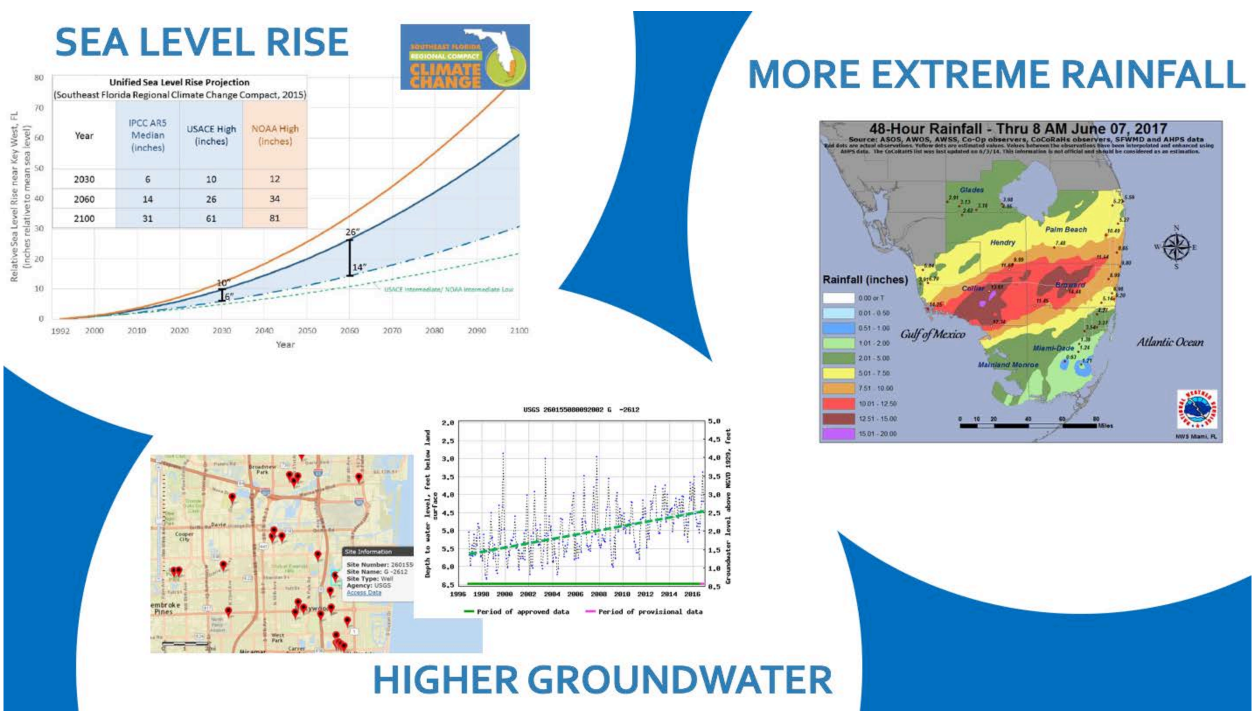

Figure 3-7. Broward County’s Challenge of Integrated Planning.
Source: Environmental Planning and Community Resilience Division, Broward County, Florida.

Nora Beck of Chicago Metropolitan Agency for Planning (CMAP) spoke about their efforts in developing a flood susceptibility index. It is widely recognized that land-use has an impact on solutions, and planners use floodplain maps to identify assets at risk. However, they do not have the tools available at the moment to plan for urban flooding beyond use of the maps. CMAP is developing an urban flood susceptibility index for the Chicago region to focus on areas outside of the 100-year floodplain in the absence of detailed regional flood and drainage models. They are using what they call the frequency ratio method. They apply this method to six factors: age of first development, sewer type, impervious cover, precipitation variation for a 10-year, two-hour storm events, elevation differential with base flood elevation, and a topographic wetness index. CMAP is using this index with their planning efforts, and the Metropolitan Water Reclamation District of Greater Chicago (MWRD) is using the index to guide priorities in their implementation of their master plan. In terms of next steps, CMAP is evaluating the relative importance of these factors to more accurately represent how they contribute to flooding in a relative sense. They are also exploring additional factors and including more recent damages in their analysis. The data and methodology can be found in their website: https://cmap.is/flood-index

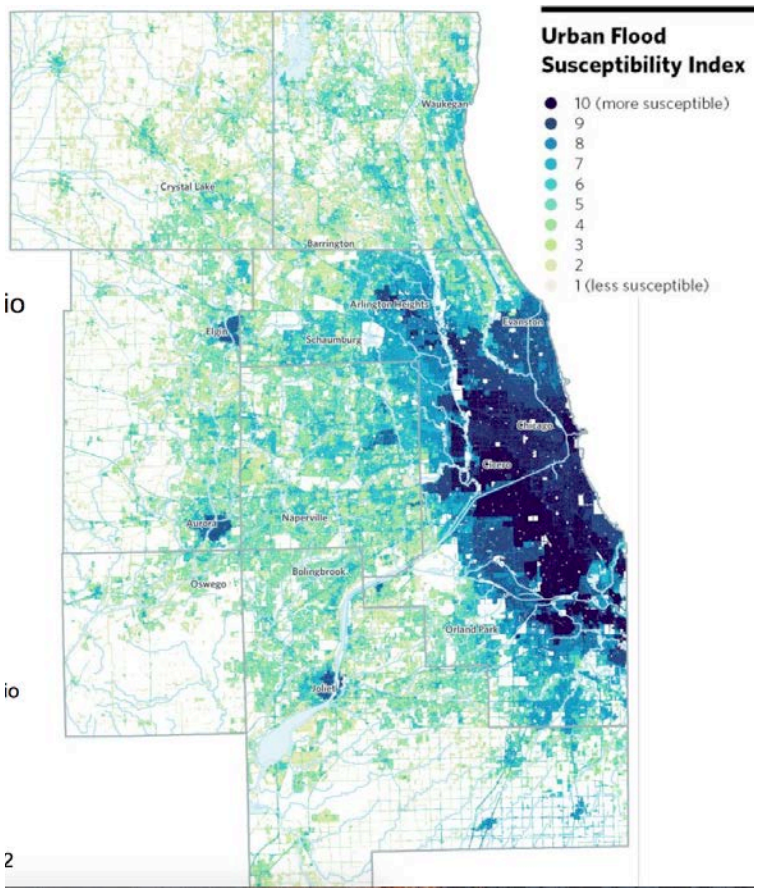

Figure 3-8. Flood Susceptibility Index for the Chicago Region.
Source: Nora Beck.

In summary, the panelists bracketed the kinds of approaches that cities and utilities are using to better integrate future climate with their existing planning tools for identifying areas and assets at risk of flooding. One-dimensional (1D) H&H models are typically used for understanding existing water quality conditions and analyzing the potential impacts of changes in water quality management. However, 2D surface flow analysis is needed to consider how rainfall flows along the surface, and coupled 1D-2D models are needed to understand how surface flow and pipe flows interact dynamically during storm events (e.g., pipe surcharging from inlets or manholes onto streets).

However, fully coupled H&H models incorporating 2D urban flood dynamics are challenging and resource-intensive to develop, calibrate, and run, especially over large urban areas. Such coupled models are yet more difficult to evaluate under a wide range of future climate scenarios given the computational requirements and potential limits to model performance outside of historically observed conditions. A loosely coupled modeling approach is more practical for most larger water utilities, but still challenging in terms of data needs and sophistication in linking the inputs and outputs of the various modeling components. At the other end of the spectrum, in lieu of modeling, some communities are making use of flood susceptibility indices that are cheaper and relatively easy to implement.

3.5 Theme 4: Policy Levers and Implementation

The Theme 4 session was structured around four break-out groups to enable workshop participants to discuss in a smaller group setting the potential next steps and develop priorities moving forward. A facilitator and note taker were chosen for each group. The names of the facilitators and participants in each group are included in Appendix C.

3.5.1 Summary of Observations from Break-out Groups

Three priorities for next steps emerged from Group 1's discussion: 1) modeling and treatment of uncertainty; 2) communication of uncertainties and risks to the public, and building a case for public action; and 3) confronting the challenges of implementation. The group also talked about: identifying barriers to collaboration among public agencies, exploiting the value of new sensors and other new technologies to improve data collection; collaborating among utilities on problem formulation and modeling approaches that could save communities time and resources; developing opportunities for large cities to advise and translate their methods to smaller communities who lack expertise and funding; and strengthening relationships between universities and utilities.

Group 2 identified two priorities in need of attention: data and modeling, and regulatory and policy opportunities. They also noted that research, funding, and considerations of equity within communities are foundational to all priorities.

Group 3 converged on several priorities: better approaches to estimating return on investment and co-benefits; improved governance or "ownership" of flooding, especially interior flooding; applications of emerging technology such as cheaper sensors or artificial intelligence for designing infrastructure; and more effective communication of flood risk as well as flood mitigation goals and metrics.

Group 4 converged on two categories of priorities: clarifications about existing and regulatory policy going forward. Within each of these categories, several sub-priorities were agreed upon. Regarding clarification of existing policy, the group believed that there would be value in seeking more direction from regulators on the level of protection; and receiving guidance on the appropriate level of effort to put into detailed modeling versus less detailed modeling/scenario analysis. For future regulatory policy, the group thought that several areas could be improved including: understanding of availability of federal support and funding; coordination among regulators to give communities more coordinated requirements; coordination among policymakers within a given level of government and across levels of government. Additionally, they thought that there would be value in creating more forums for discussion of regulatory policy options, and coordination with businesses who are inclined to be proactive and therefore seeking more certainty for their own planning.

3.5.2 Synthesis of Research Priorities Across the Break-Out Groups

Following the group discussions and report-outs from each group, the workshop organizers requested that all participants vote on their top three priorities emerging from these discussions. The top five priorities in which action is needed now were:

1. Communication with the public of uncertainty, risk, and justification of actions, particularly with underserved communities.
2. Improved governance of stormwater management, drainage, and flooding at the local and federal levels.
3. Better resourced and sustained data collection and analysis.
4. Improved methods of estimating economic and non-monetary return on investments and co-benefits, given the differences that now exist between agencies and cities.
5. Clarification of desired levels of protection from regulators and the public.

These priorities are further discussed in Chapter 5 in the context of actions that could be taken by governing bodies at all levels.

3.6 Key Take-Aways from Panel Presentations and Discussions

Water quality regulatory requirements have thus far been driving actions by utilities to integrate the management of wastewater and stormwater. But it has also become apparent that urban stormwater flooding is itself a difficult and nationwide problem and brings to the fore concerns about equity among communities in need of timely responses. Water utilities in cities across the country are struggling to keep up with increasing incidence of extreme rainfall events of increasing intensity and duration. Further, cities and their utilities are working within the constraints of existing water quality regulation and consent orders that can limit their efforts to take a more integrated approach to stormwater management. As a general matter, efforts in urban areas to meet current water quality control requirements while managing growing and persistent flooding risks consist of one or more of the following strategies: 1) slow the entry of stormwater into the drainage network; 2) move excess water away from at-risk areas; 3) secure individual properties in high-risk areas; 4) predict and manage the movement of stormwater using technologies that allow for real-time response to flooding events; 5) build up emergency response capabilities throughout the city; and 6) increase the capacities of their drainage and collection systems if necessary.

Workshop participants agreed on the value of integrated planning methods despite the administrative and regulatory barriers that exist locally and within the structure of federal environmental law. Stormwater management is closely connected to land use and land values, and as such, broader utility strategies to mitigate urban flooding from extreme rainfall events will require ongoing communications and engagement with individual communities.

At present, however, there is no federal guidance as yet on how to reconcile the statutory and regulatory structure in place to address water quality while also integrating management of stormwater. While this situation may lead to the exploration of many different approaches at the local level, it leaves cities in a difficult position in terms of both policy guidance and funding. The aim would be to move from a “least cost” to “highest value” approach to integrated infrastructure investment and risk-mitigating actions. Many cities are moving forward with ambitious projects for green stormwater infrastructure to remain in compliance with their water quality standards, despite difficulties in estimating the levels of reduction they can achieve and modeling their co-benefits.

Climate modeling and projections present formidable, but surmountable technical challenges. GCMs cannot provide projections about when, where, and how frequently these extreme events will occur.

Instead, scenario-based and other methods will need to be employed in the foreseeable future to enable urban areas to move forward with their adaptative planning.

Several modeling methods were presented for representing extreme precipitation and urban flooding. Less technical, non-modeling index-based approaches may offer a "walk before you run" strategy for utilities not ready to commit to more sophisticated modeling approaches before those approaches have been more fully developed, tested, and proven effective elsewhere.

In the end, there is not as yet a consensus as to what methods for climate-resilient modeling, planning, and design are preferred or could be considered best practice at this time. However, there was a consensus on the need for: higher resolution data and models to feed into planning efforts, measuring co-benefits of proposed flood mitigation solutions (i.e., green infrastructure) in the context of water quality constraints, and better communication of uncertainties to communities, regulators, and decision makers.

Finally, cities and their utilities are facing immediate needs. There remain serious difficulties in accessing emergency funds from FEMA following a major flooding event. This is a particular problem for stormwater management measures, which tend to be funded through utility rates based on standard drainage and water quality needs – not with extreme events in mind.

Chapter 4 describes and summarizes findings from pre- and post-workshop surveys of participants, followed by a further discussion in Chapter 5 of key messages, conclusions, and next steps drawn from the panel and breakout sessions.

CHAPTER 4

Survey Methods and Findings[5]

The workshop's evaluation team assessed the interests, knowledge, and perceptions of water management professionals who participated in workshop. The main objective of the assessment was to provide a snapshot before and after the workshop of participant's knowledge and perceptions of climate data, integrated modeling, and factors perceived to influence effectiveness of water planning and management.

A brief survey was administered before and after the workshop to evaluate participants' interests, knowledge, and perceptions of the workshop. A total of 23 pre-workshop surveys and 34 post-workshop surveys were completed. Results indicated that participating technical experts and other water professionals found the workshop to be engaging and useful. Additionally, although participants rated themselves as well-informed about climate impacts on water management prior to the workshop, they indicated they were even better informed after the workshop. Several suggestions for future workshops were offered, including alternative topics (e.g., financial or economic aspects of water management), additional participants (e.g., planners, policy makers); and format changes (e.g., more opportunity for group discussions about solving climate challenges).

4.1 Methods

Participants were asked to complete a short, online survey one week prior to (n=43), and a paper survey immediately after (n=42), the workshop. A total of 25 respondents initiated at least some responses to the pre-workshop survey (response rate = 58%) and 34 respondents completed a post-workshop survey (response rate = 81%). Characteristics of each set of respondents are shown in Table 4-1. To maintain confidentiality, no identifying information was collected; thus, surveys completed pre- and post-workshop could not be linked to the same individual.

[5] Melissa Finucane, Senior Behavioral and Social Scientist, RAND Corporation; and Ivy Todd, Research Assistant, RAND Corporation are the authors of this chapter and members of the MARISA team. They developed the surveys, analyzed the findings, and wrote the text.

Table 4-1. Respondent Characteristics.
(Percentages add to less than 100 in some instances because some data are missing.)

Attributes of Respondents	Pre-Workshop Sample (n=25)	Post-Workshop Sample (n=34)
Gender, n (%)		
Male	9 (43%)	17 (50%)
Female	12 (57%)	17 (50%)
Education, n (%)		
4-year college graduate	6 (29%)	5 (15%)
More than 4-year college degree	15 (71%)	29 (85%)
Ethnicity and race, n (%)		
Hispanic or Latino	1 (5%)	2 (6%)
Black/African American	3 (14%)	4 (12%)
White/Caucasian	16 (76%)	26 (79%)
Asian	0 (0%)	1 (3%)
Primary professional activity, n (%)		
Director of a private or public organization	5 (24%)	9 (26%)
Technical expert (e.g., planner, natural resource manager, hydrologist, engineer) at a private or public organization	8 (38%)	12 (35%)
Representative of a non-governmental organization with a special interest or focus	2 (10%)	3 (9%)
Policy Analyst/Advisor/Researcher	3 (14%)	5 (15%)
Other	3 (15%)	5 (15%)
Professional time spent working on planning for management of stormwater and wastewater, n (%)		
All or a lot of my time	7 (33%)	15 (44%)
About half my time	5 (24%)	7 (21%)
Some or almost none of my time	9 (43%)	12 (36%)

Both the pre- and post-workshop surveys (see Appendix C) asked for background information about respondents (gender, education, ethnicity/race, professional activities). Both surveys also asked respondents to indicate how well-informed they were on several topics about impacts of a changing climate on stormwater and wastewater planning and management. Respondents also were asked to indicate in both surveys their ratings of factors that influence the effectiveness of water management efforts. Unique to the pre-workshop survey was a question asking respondents about topics and activities that they would be interested in learning about during the workshop. Finally, only the post-workshop survey asked participants to rate the usefulness of the workshop.

This survey activity was approved by the RAND Corporation's Human Subjects and Protection Committee.

4.2 Findings

4.2.1 Interest in Various Topics and Activities

Prior to the workshop, respondents indicated their interest (extremely, moderately, a little, not at all) about a range of topics and activities (see Table 4-2). The majority of respondents (70%) were extremely interested in identifying future climate scenarios for stormwater and wastewater planning under uncertainty. More than half of the respondents were extremely interested in all but one of the other topics presented.

Table 4-2. Number and Percentage of Respondents Extremely Interested in Specific Topics and Activities (pre-workshop survey only).

Topic	Extremely Interested
Identifying future climate scenarios for stormwater and wastewater planning under uncertainty (n=23)	16 (70%)
Identifying new methods for managing urban stormwater and wastewater (n=24)	15 (62%)
Learning how to integrate climate data with existing hydrology models (n=24)	14 (58%)
Identifying best practices for managing urban stormwater and wastewater (n=25)	14 (56%)
Learning about simulation modeling for evaluating cross-sectoral approaches to long-term resiliency (n=23)	13 (57%)
Building capacity to implement new integrated planning methods (n=24)	13 (54%)
Sharing ideas to inform more robust urban stormwater and wastewater infrastructure strategies to meet future needs (n=25)	13 (52%)
Learning how to address regulatory barriers to the use of climate data and integrated modeling (n=25)	9 (36%)

When prompted with an open-ended question asking for additional suggestions, seven respondents provided additional topics they were interested in learning about. Several of these suggestions focused on financial or economic aspects of water management:

- Financial regulatory barriers that adversely affect flood mitigation on private property.
- How water utility business structures enable/hinder water climate resilience, and how resilience investments can become part of operating costs.
- Working with the private sector and public-private partnerships to build long-term capacity for overall integrated water management and for smart, on-site stormwater management (interception and treatment) and conservation with traditional and hybrid systems.
- Climate change funding and environmental permitting.
- General information about how climate science practitioners work around financial constraints in communities.

Other topics suggested more traditional topics were of interest, including: vulnerability and risk assessment and response; climate resiliency design guidelines and standards; adaptive infrastructure planning; social risk management and environmental justice; institutionalization, training, and process improvement; and methods to inform the public about risk.

4.2.2 Self-Reported Knowledge

Respondents were asked to rate how well-informed they were (extremely well informed, fairly well informed, not well informed, not at all informed) on a range of topics in both the pre- and post-workshop surveys (see Table 4-3). Prior to the workshop, the majority of respondents indicated they were extremely or fairly well-informed about the likelihood and consequences of a changing climate for stormwater and wastewater management. Ratings were more mixed pre-workshop for knowledge about: how to prepare for or manage water under future conditions; how to integrate data or use simulation modeling for planning; or regulatory barriers to the use of climate data or integrated modeling. The post-workshop ratings indicated that respondents felt their knowledge about these same topics had improved.

Table 4-3. Respondents' Rating Pre- and Post-Workshop of Their Knowledge of a Range of Topics (n, %).

Topic		Extremely well informed	Fairly well informed	Not well informed	Not at all informed
The likelihood of changes to stormwater or wastewater as a result of a changing climate	*Pre-workshop (n=22)*	4 (18%)	18 (82%)	0 (0%)	0 (0%)
	Post-workshop (n=34)	10 (29%)	24 (70%)	0 (0%)	0 (0%)
The consequences of a changing climate for stormwater or wastewater management	*Pre-workshop (n=22)*	5 (23%)	17 (77%)	0 (0%)	0 (0%)
	Post-workshop (n=34)	15 (44%)	17(50%)	2 (6%)	0 (0%)
How to prepare your organization for changes to stormwater or wastewater as a result of a changing climate	*Pre-workshop (n=22)*	1 (4%)	10 (45%)	1 (4%)	10 (45%)
	Post-workshop (n=32)	4 (12%)	18 (56%)	8 (25%)	2 (6%)
Methods for managing stormwater or wastewater under future conditions	*Pre-workshop (n=22)*	1 (4%)	12 (54%)	9 (41%)	0 (0%)
	Post-workshop (n=34)	4 (12%)	23 (68%)	6 (18%)	1 (3%)
Planning methods that integrate climate and hydrology information	*Pre-workshop (n=22)*	4 (18%)	11 (50%)	1 (4%)	6 (27%)
	Post-workshop (n=34)	8 (24%)	20 (59%)	6 (18%)	0 (0%)
Simulation modeling for evaluating cross-sectoral approaches to long-term resiliency	*Pre-workshop (n=22)*	1 (4%)	7 (32%)	2 (9%)	11 (50%)
	Post-workshop (n=30)	8 (27%)	12 (40%)	7 (23%)	3 (10%)
Regulatory barriers to the use of climate data and integrated modeling	*Pre-workshop (n=21)*	3 (14%)	3 (14%)	2 (9%)	13 (62%)
	Post-workshop (n=34)	6 (18%)	22 (65%)	5 (15%)	1 (3%)

4.2.3 Factors Perceived to Influence the Effectiveness of Stormwater and Wastewater Management Efforts

Respondents were asked to rate their agreement or disagreement (strongly agree, agree, disagree, strongly disagree) with a range of factors that might influence the effectiveness of stormwater and wastewater management efforts in both the pre- and post-workshop surveys (see Table 4-4). Respondents (both before and after the workshop) tended to agree that several factors were most influential: the need for an integrated management plan; a tendency for professionals to stay within their communities of practice; uncertainty about future conditions; and the need for new market-based instruments. Existing regulatory frameworks and consensus-building across municipalities were considered relatively less influential on management efforts.

Table 4-4. Number (and percent) of Respondents Pre- and Post-Workshop Who Strongly Agree or Agree With Specific Factors Influencing Stormwater and Wastewater Management Efforts.

Factor	Pre-Workshop	Post-Workshop
We need a stormwater and wastewater management plan that integrates across the approaches of multiple municipalities.	20 (95%)	30 (94%)
People involved in planning for the management of stormwater and wastewater tend to remain within their networks or communities of practice.	20 (90%)	25 (78%)
Uncertainty about future conditions is used to justify non-action during discussions about planning for effective management of stormwater and wastewater.	17 (81%)	21 (66%)
We need to consider new market-based instruments to improve the effectiveness of the management of stormwater and wastewater.	15 (72%)	26 (81%)
Existing regulatory frameworks support effective management of stormwater and wastewater in my region.	8 (38%)	9 (28%)
Building consensus for a stormwater and wastewater management plan that integrates across multiple municipalities is unlikely.	6 (29%)	11 (34%)

4.2.4 Workshop Evaluation

Following the workshop, the vast majority (91%) of respondents indicated they would like to participate in a similar workshop again in the future. Most respondents indicated that overall the workshop was either extremely useful (74%) or moderately useful (24%). Other ratings indicated that the main objectives of the workshop were met, discussions were facilitated well, and comments and ideas were captured appropriately.

In response to an open-ended question asking about key experts or others who should be included in a future, similar workshop, respondents suggested: planners and design engineers; other federal agencies (e.g., FEMA, EPA); additional local government and utility agencies; legislators and policy implementers; and representatives from communities in more arid regions of the West. Several respondents indicated that they thought the workshop had good representation.

Finally, when asked for suggestions for improving the format or content of the workshop, the majority of comments (n=8) were about the breakout/discussion sessions. In particular, participants wanted fewer or shorter presentations and more time to discuss the topics in breakout groups. A few respondents added that they would have preferred more structured breakout group discussion with specific topics or prompts. One respondent suggested spending more time discussing climate solutions and less discussing challenges; another suggested discussing other results of climate change (such as drought and heat) rather than just flooding.

4.3 Discussion

These surveys assessed the interests, knowledge, and perceptions of professionals who participated in the workshop. Findings suggests that the workshop was of keen interest to and very useful for participants. Prior to the workshop, respondents showed interest in a range of topics related to climate-resilient planning, including identifying future climate scenarios and learning new or best management practices. Self-ratings suggested that although respondents were well-informed about climate impacts on water management prior to the workshop, the group rated themselves even more well-informed after the workshop. Little change was noticed pre- to post-workshop regarding the factors that respondents considered influential on the effectiveness of stormwater and wastewater management efforts. Overall, the majority of respondents considered the workshop to be useful and something they would participate in again.

Suggestions for future workshops included: 1) focusing on topics about the financial or economic aspects of water management, including barriers and opportunities; 2) including more planners and policy makers at all levels (federal through local) as participants; and 3) providing more opportunity for deeper group discussions of solutions to the challenges of climate impacts on stormwater and wastewater management.

CHAPTER 5

Conclusions

5.1 Synthesis of Key Messages

Wastewater utilities have historically been organized around planning, operations, and compliance within a well-established regulatory structure for meeting water quality standards. Such a regulatory structure does not as yet exist for stormwater and urban flooding, making its integration and priority for utility managers all the more challenging. In light of the increasing frequency of extreme precipitation events, increasing levels of urbanization and associated impervious cover, sea level rise in coastal cities, and the uncertainty surrounding projection of trends and magnitudes in the future, utilities are facing analytical challenges as they develop or modify their operational and infrastructure investment strategies to accommodate future rainfall volumes. These issues are affecting utilities across the country in coastal and inland cities.

5.2 Research Needs to Support Future Action

The workshop not only provided a forum for discussing the various approaches that utilities are testing and applying in the absence of a consensus around best practices, but also offered an opportunity for participants to identify priorities for research in support of future management and investment actions. Priorities for research are organized within the following categories:

1. Governance arrangements for integrating stormwater management into water quality, water supply, drainage, and flood protection.
2. Need to establish a basis for levels of protection from urban flooding.
3. Data collection, modeling, and analysis incorporating climate projections into an integrated framework.
4. Valuation of return on investment, including co-benefits of stormwater management strategies.
5. Approaches to communicating risk, uncertainty, and benefits to the public and decision makers.

5.2.1 Integrating the Governance of Stormwater Management, Drainage System Design, and Flood Risk Mitigation

Problem Statement: Agencies attempting to responsibly manage the interdependencies of water quality on proper management of stormwater are caught in a gap in federal programs. Stormwater management is one of several strategies for regulating the water quality of receiving waters within the current federal regulatory structure of the Clean Water Act administered by the EPA with substantial delegation of authority to the states. To this end, U.S. EPA regulatory standards, enforcement actions, and funding resources made available to local utilities through the State Revolving Fund program are focused on improving water quality rather than addressing both water quality and flood control objectives.

Drainage has historically been a local concern, without federal involvement other than the situations affecting wetlands areas under EPA’s definition of waters of the United States. The CWA requires that dredging or filling wetlands be contingent on a Section 404 permit, a program administered by the U.S. Army Corps of Engineers (USACE). Drainage control does not necessarily include flood control measures. In addition, the USACE operates an emergency flood control repair and rehabilitation program for non-federal projects damaged by floods through what is known as the Public Law 84-99 program (USACE 2009). Local entities are not required to participate, but participation enables access Federal funds to repair damage to infrastructure in the event of a disaster. The USACE also reviews and approves any proposed public or private modifications to existing federal flood control projects through their Section 408 authority (USACE 2018a and 2018b).

Flood control has been handled historically by local and regional authorities, but is not regulated directly. Instead, the National Flood Insurance Program (NFIP) requires that properties located in designated “100-year” flood zones purchase flood insurance. (NFIP was authorized by Congress because of the reluctance of private insurers to offer flood insurance.) However, because only properties that are designated as high-risk are required to purchase insurance, a disproportionate number of insured properties in the NFIP pool are high-risk. Uptake of flood insurance is uneven throughout the country (Dixon et al. 2006 2017). Furthermore, urban (pluvial) flooding is not typically well characterized outside of coastal or riverine floodplains, in part due to modeling and data limitations noted previously.

Some localities are beneficiaries of USACE-built flood control projects. These projects are individually authorized by Congress and require a cost-sharing agreement between the USACE and the local sponsor before construction. The local sponsor may or may not be a storm water or wastewater utility, complicating the task of integrating flood control with planning and design of storm water, water quality, and drainage system-related infrastructure.

No examples of cities could be identified that consider flooding as part of integrated water management. Indeed, many cities are struggling to bridge this gap. Among those cities represented at the workshop, the Philadelphia Water Department represents a helpful example of a utility moving toward more integrated management of CSOs and drinking water including watershed protection, offering some potential flexibility to address urban flooding in the process.

FEMA will soon be releasing new maps that show the likelihood of inland and urban flooding throughout the nation. Exposing these risks explicitly raises a challenging governance issue: a federal agency is furthering its statutory role in risk identification but leaving local utilities and governments to address these risks – and fund them. While FEMA does offer local governments selected opportunities to apply for pre-disaster funds, FEMA’s post-disaster funding approach is not well-aligned with managing stormwater flooding at scale (e.g., watershed management). U.S. Army Corps of Engineers projects pose similar challenges and limitations. Instead, individual stormwater projects are considered separately, and often cannot pass benefit-cost criteria for flood damage reduction in isolation.

Research Need: Better understanding the nature and extent of this problem and developing and analyzing the efficacy of possible policy remedies is a top research priority.

5.2.2 Establishing a Basis for Levels of Protection from Urban Flooding

Problem Statement: Regulators, agencies, and utilities alike are seeking guidance on how to set appropriate levels of protection – such as clearly defined flood risk frequency or intensity standards – to guide to guide investments in stormwater controls and mitigation measures. This situation stands in stark contrast to the highly regulated environment that drives investments in pollution control, receiving water quality, and drinking water quality. Workshop participants noted that each municipality seems to have its own design criteria with little or no standardization, for example, in methods of selecting design storms or target capture volumes. It is unclear what the attributes, efficacy, and implications of a more prescriptive approach would even look like. In addition, design storm-based approaches are challenged by a non-stationary climate, where design assumptions are made assuming historical rainfall patterns will no longer hold under future conditions.

Research Need: There would be value in research that builds on analytical methods that avoid the “design storm” approach entirely and instead focuses on reducing overall vulnerability using decision analytics and decision support methods such as robust decision making.

5.2.3 Improving Data and Models to Characterize Current and Future Risks

Problem Statement: Utilities rely on extensive data collection networks for water quality and flows through their conveyance systems. However, they are often operating with inadequate information when managing stormwater flows during intense precipitation events. Precipitation and streamflow are two critical datasets, for instance, but in most areas, neither the spatial nor temporal resolution of existing data sets is satisfactory, and many gauges only provide a limited record of historical observation. Urban flooding is difficult to estimate and manage in the absence of good data on incoming rainfall, streamflow, and system flows on a time scale of minutes to hours.

Data resolution and quality are particularly pressing issues in rainfall measurement. Rain gauges are typically dispersed throughout a city, and simply too geographically dispersed to capture most extreme events for real-time observations, making it difficult to understand and characterize past events or project the impacts of future extreme events. Urban flooding is difficult to estimate and manage in the absence of good data on incoming rainfall, streamflow, and system flows on a time scale of minutes to hours. Many gauges also fail to record rainfall at 15-minute intervals or less, which can be vital to understanding the temporal characteristics of extreme events. Some cities are moving towards using more radar-derived data for this reason.

Most utilities rely on H&H models calibrated with limited monitoring data to estimate system flows, sewer overflows, and other water quality outputs. However, another key challenge – and distinct from the practical challenges of generating rainfall projections for input to the H&H models -- is the inadequacy of existing hydrologic and hydraulic modeling tools to simulate urban flooding as part of integrated systems (e.g., combined surface and pipe flow). The state of the art of modeling has not advanced enough to offer a guide on best practice for how to structure models, determine appropriate scales for simulation, and how to integrate or couple surface flow or flood models with well-established water quality models.

Research Need: This is a hard and as yet unsolved problem that requires significant attention of researchers and funders to develop a basis for guidance on how to identify and implement best practices. It is also exacerbated by the data limits noted previously—in particular to support model calibration and validation—as well as confounding land use factors. The inadequacy of current models may ultimately necessitate the development of new integrated modeling tools.

In general, data and modeling issues place serious limitations on utilities seeking to incorporate climate projections into their planning processes. It also challenges their ability to estimate the potential benefits from stormwater projects intended to mitigate flood impacts. Neither statistical nor dynamical downscaling of global climate model outputs can as yet provide meaningful projections of extreme precipitation at needed spatial or time scales.

5.2.4 Estimating Benefits, Co-Benefits, and Return on Investment for Stormwater Projects

Problem Statement: Data and modeling limitations noted previously pose overall challenges to projecting benefits or comparing investment options. Even when benefits of reduced flooding can be estimated, there remains the challenge of fully capturing other indirect benefits (co-benefits) that might accrue from some of these stormwater mitigation measures. At an individual project level, the small scale of many green stormwater infrastructure projects further complicates the task of estimating direct and indirect benefits. At the same time, costs of such geographically diffuse initiatives are packaged into a single consolidated project cost at the utility-scale, making it difficult to estimate a rate of return on investment. Further, benefits take time to accrue when the individual local components of green infrastructure are being built over time. Until the whole project is fully built out and operating, benefits cannot be properly estimated.

For example, quantifying the costs associated with flood-induced disruption of business operations, schools, and commerce as well as health impacts on the affected population could be significant in many locations. Co-benefits from GSI in terms of recreational opportunities, ecosystem services, and other community benefits can also be important to local decision making. As such, these co-benefits also belong in the estimation of return on investment and play a role in the valuation of these investments relative to others.

Research Need: A key research challenge is the quantification of benefits and co-benefits of investments in mitigating impacts of stormwater flooding, particularly when many of the actions are highly decentralized.

5.2.5 Communicating Uncertainty, Risk, and Tradeoffs

Problem Statement: Managing stormwater in the face of climate, regulatory, and funding uncertainties requires utilities to be sophisticated in their communications with the public about risks and the trade-offs entailed across multiple and sometimes competing public objectives.

Research Need: More research guidance on how to incorporate the uncertainties associated with climate projections into their planning processes, and for communicating those uncertainties and risks of a changing climate to regulators, residents, public officials, and other stakeholders.

In addition, investments to mitigate impacts of extreme precipitation events and urban flooding that may result are competing with other water-related investments. Stormwater not only poses flood risk, but also risk in the form of missed water quality regulatory standards. For this reason, it is imperative that the risk-reduction and other benefits of these investments are characterized appropriately, enabling decision makers to understand the nature of the trade-offs among competing public objectives.

5.3 Next Steps to Advance the Research and Best Practice

Against the backdrop of changing frequency, intensity, and duration of extreme precipitation events in many places, the workshop provided an opportunity for participants to share their collective experience in coping with urban flooding and its damage to property, disruption of commerce, and degradation of water quality. Utilities across the country are stepping up to alleviate the impacts of these extreme events in their communities but without the benefit of clarity about how to integrate stormwater management within existing governance structures and regulatory obligations. The workshop demonstrated the creativity of on-going efforts by utilities to devise reasonable ways to proceed, even without adequate data and modeling tools, but also identified a challenging research agenda for the years ahead to enable progress toward establishing best practices.

The organizers of this workshop envision three lines of effort to further advance research and best practice:

1) Work with a WUCA subcommittee to continue encouraging exploration of new approaches and sharing lessons learned and experience gained among large utilities. WUCA is in a strong position to play a leadership role through its unique position and convening power within the sector. Additional partnerships with other organizations will be highly beneficial in bringing additional perspectives to these conversations.

2) Share lessons learned from the workshop through additional workshops and other convening opportunities with other critical organizations including, for example, the American Water Resources Association (AWRA), the American Society of Civil Engineers / Environmental and Water Resources Institute, the Association of State Floodplain Managers (ASFPM), the National Association of Flood and Stormwater Management Agencies (NAFSMA), and the American Planning Association (APA). In addition, these convenings should also target broader audiences, including a) small- to mid-sized utilities

who could benefit from learning about the experiences of the larger utilities, and b) the broader network of stakeholders engaged in urban stormwater and integrated water planning.

3) Identify funding opportunities suitable to addressing the research needs noted earlier in this chapter. The aim here would be to continue to engage current funders but also pursue government and philanthropic funding to fill some of these gaps in both research and practice. This effort could also include consideration of new ways that utilities might pool resources to achieve shared research objectives such as those that emerged from this workshop.

In sum, the authors seek to continue working with partners to pursue the research agenda described here and continue promoting opportunities for information sharing among utilities and others seeking to improve the integration of climate projections into an integrated water management framework.

APPENDIX A

Workshop Agenda

Day 1: July 16, 2019

10:00 am Optional Tour of the Newtown Creek Wastewater Resource Recovery Facility

12:00 pm Lunch

1:00 pm Welcome and Opening Remarks

1:30 pm Plenary Panel: Stage Setting

The plenary panel will set the stage for entire workshop, providing an overview of the current state of the art for urban stormwater and wastewater planning in the face of climate and other uncertainties. The goals include:

- Introduce and describe the problem this workshop will address
- Establish a common level of understanding across the group

Panelists will also introduce the four themes we will explore in further depth through the remainder of the workshop, including the challenges of integrated planning within today's regulatory context; climate resilience and scenario inputs; modeling and uncertainty analysis; policy levers and implementation.

3:00 pm Break

3:15 pm Theme 1 Panel: Integrated Infrastructure Planning and the Current Regulatory Context

The first theme focuses on the range of operational and planning objectives that stormwater and wastewater utilities are trying to achieve now and in the future. Utilities in this sector must work towards a range of different objectives at once, and policy decisions or investments to help achieve one objective may help or hinder progress towards others. Some objectives tie directly to legal or regulatory requirements, while others may emerge in response to location-specific vulnerabilities or hazards. Utilities must also recognize that public agencies, local stakeholders, and community members may have differing preferences about the relative importance of objectives, and need to be able account for these perspectives when resolving tradeoffs and making decisions.

Guiding questions for this discussion include:

- What are the necessary elements of integrated stormwater and wastewater infrastructure planning to manage flows, meet water quality standards, and protect ecosystems?
- Are different objectives moving up or down the priority list in response to changing conditions, either at present or projected in the future?
- How should economic impacts be assessed to support an integrated planning process?
- How might utilities incorporate differing preferences and perspectives and resolve tradeoffs when making capital or operational decisions?

5:30 pm Wrap-up for the day

Day 2: July 17, 2019

8:30 am — Theme 2 Panel: Climate Resilience and Scenario Inputs

The third workshop session will focus on how historical and climate projected rainfall estimates are being used to inform planning and decision making. Panelists will discuss the state-of-the-art regarding how hydrologic uncertainties are being represented and applied, approaches to understand and characterize extreme precipitation given a changing climate, and key questions utilities still need to address to establish best practices for incorporating climate and hydrology uncertainty into near- and long-term plans.

Guiding questions include:

- What approaches to hydrologic uncertainty are currently being used (e.g., historical analogs, downscaled time series, modified Intensity Duration Frequency (IDF) curves), and what are their strengths and weaknesses?
- What lessons can be learned from the use of climate scenarios for water supply planning?
- What existing inputs and approaches are available for projecting future rainfall patterns, including extreme events, and land use changes?
- What are the key gaps and what tools are needed to resolve them?

10:15 am — Break

10:30 am — Theme 3 Panel: Continuum of Modeling Tools and Model Integration

This session will focus on new and innovative approaches to develop and apply simulation models, in isolation or combination, to support climate-resilient storm and wastewater planning. Modeling tools to be discussed are those intended to inform the planning goals discussed in Theme 1 and include representations of water flows (e.g., hydrologic and hydraulic models), natural or engineered systems, and/or human systems, as well as their interrelationships. Panelists will discuss a range of approaches, from "rule of thumb" guidelines to high-resolution and/or integrated simulation modeling suites.

Key guiding questions include the following:

- What are the advantages and limitations of modeling and planning/design tools, ranging from traditional engineering approaches to more sophisticated simulation models?
- How should utilities consider and resolve the tradeoffs between model resolution and cost/computational intensity (e.g., 1D vs. 2D analysis to inform urban flood planning)?
- What are the key data requirements for building and calibrating effective simulation models, and where gaps in data availability most evident or challenging?
- What does model integration actually mean in practice?

12:00 pm — Lunch

1:00 pm — Theme 4 Break-Out Groups: Synthesis of Workshop Insights and Next Steps

In this session, workshop participants will break into four groups to discuss key take-aways from the previous panels and consider priorities for action.

Guiding questions include:

- What do you consider the top three priorities to emerge from the workshop?
- For each of your priorities, what might be the key enablers or constraints that would determine whether progress could be made within the next 12 to 24 months?
- Which of these priorities might be top candidates for collaboration among the utilities?

2:30 pm Next Steps and Wrap-up

3:00 pm Adjourn

APPENDIX B

Workshop Participants and Speaker Biographies

B.1 Participant List

Table B-1. Participant List.

Last Name	First Name	Affiliation	Title
Acock	Kristen	City of Portland Bureau of Environmental Services (OR)	Stormwater System Division Manager
Adams	Peter	New York City Mayor's Office of Recovery and Resiliency	Senior Policy Advisor For Infrastructure
Ancel	Susan	EPCOR	Director of Stormwater Strategies
Asefa	Tirusew	Tampa Bay Water/WUCA	Planning and Decision Support Manager
Baja	Kristin	Urban Sustainability Directors Network	Programs Director, Climate Resilience
Balci	Pinar	NYC DEP	Assistant Commissioner, Bureau of Environmental Planning and Analysis
Beck	Nora	Chicago Metropolitan Agency for Planning	Senior Planner
Beckhardt	Larry	NYC DEP	Deputy Chief
Beller-Simms	Nancy	NOAA Climate Program Office	Program Manager for the Sectoral Applications Research Program
Bonard	Nicholas	District of Columbia Department of Energy and Environment	Chief of the Water Resources Protection and Mitigation Branch
Brock	John	NYC DEP	Policy Analyst
Cammarata	Marc	Philadelphia Water Department	Deputy Water Commissioner, Planning
Cherrier	Jennifer	City University of New York Brooklyn College	Professor and Department Chairperson
Chisolm	Rachel	City of Austin; Austin Water, Systems Planning	Graduate Engineer
Cohn	Alan	NYC DEP	Managing Director, Integrated Water Management
Fischbach	Jordan	RAND Corporation	Senior Policy Researcher
Flores-Gonzales	Marisa	Austin Water/WUCA	Water Forward Program Manager
Forrest	Yvonne	Houston Water	Deputy Director
Galloway	Gerald	University of Maryland	Research Professor
Glenn	Equisha	City College of New York	PhD Candidate
Hanley	Kevin	NYC DEP	Chief of Modeling and Analysis
Horton	Radley	Columbia University/NASA GISS, CCRUN	Research Professor, PI CCRUN
Ikert	Amanda	C40	Director, Water and Adaptation Initiative
Kimball	Nathaniel	New York City Mayor's Office	Senior Policy Advisor, Infrastructure and Energy
Kimes	Tom	Kansas City Water	Stormwater Utility Engineering Manager
Knopman	Debra	RAND Corporation	Principal Researcher
Kratzer	Joseph	Metropolitan Water Reclamation District of Greater Chicago	Managing Civil Engineer
Lackey	Katy	US Water Alliance	Program Manager
Maimone	Mark	CDM Smith	Senior Vice President
Maran	Carolina	Broward County (FL)	Water Resources Manager
Mecray	Ellen	NOAA	Regional Climate Services Director, Eastern Region
Montalto	Franco	Drexel University/CCRUN	Associate Professor
Morey	Erin	NYC DEP	Director, Demand Management and Resilience Policy
Olson	Charles	NYC DEP	Chief at Bureau of Water and Sewer Operations
Owens	Emmet	NYC DEP	Water Quality Modeling Section Chief

Parris	Adam	Science and Resilience Institute at Jamaica Bay (NYC)	Executive Director
Ribiero	Pedro	C40	Project Officer, Adaptation Initiative; manages the Urban Flooding Network
Robinson	Brent	Seattle Public Utilities	Strategic Advisor
Roche	Anna	San Francisco Water	Climate Change and Special Projects Manager
Rockwell	Julia	Philadelphia Water	Climate change Adaptation Program Manager
Romita Grocholski	Krista	RAND Corporation	Associate Physical Scientist
Rosenzweig	Bernice	City University of New York	Manager of TRELLIS Project and Research Associate
Rufo-Hill	James	Seattle Public Utilities/WUCA	Climate Adaptation Specialist
Simpson	Caitlin	NOAA Climate Program Office	Director, RISA Program
Tam	Wing	City of Los Angeles Watershed Protection Program	Assistant Division Manager
Ternieden	Claudio	Water Environment Federation	Senior Director of Government Affairs and Strategic Partnerships
Washington	Valerie	RAND Corporation	Summer Associate
Zhang	Harry	The Water Research Foundation	Program Director

B.2 Speaker Biographies

B.2.1 Gerald Galloway, University of Maryland

Gerald E. Galloway, PE, Ph.D. is a Glenn L. Martin Institute Professor of Engineering, Department of Civil and Environmental Engineering, University of Maryland, a Faculty Fellow of the Hagler Institute for Advanced Study Texas A&M University and a visiting professor at the A&M Galveston Campus. His teaching and research focus is on water resources policy, resilience, and disaster risk management under climate change. He serves as a consultant to several international, federal, state and non-governmental agencies and has been involved in water projects in the US, Europe, Asia and South America. In 1993, he was assigned to the White House to lead the study of the Great Mississippi Flood of that year. From 2008-2018 he was a member of the Louisiana Governor's Advisory Commission on Coastal Protection and Restoration and is currently a Governor's appointee to the Maryland Coast Smart Council. In 2014, he was appointed chair of an international panel of experts to examine the flooding threats to Florence, Italy and by the government of Singapore to a panel of experts advising on sea- level rise challenges. He is an elected member of the National Academy of Engineering, the National Academy of Public Administration, and the National Academy of Construction, and a 38-year veteran of the US Army who retired as a Brigadier General and Dean (Chief Academic Officer) at the U.S. Military Academy at West Point.

B.2.2 Claudio Ternieden, Water Environment Federation

Claudio is the Senior Director for Government Affairs at WEF and directs WEF's legislative and regulatory efforts in Washington, D.C. Claudio oversees policy development and implementation in the water sector on issues related to resiliency, infrastructure funding, green infrastructure, technology transfer and innovation. Claudio has led research efforts at the Water Environment Research Foundation (now The Water Research Foundation) related to climate change and extreme events; contributed to the development of federal regulations at the U.S. Environmental Protection Agency and the development and implementation of water quality standards in the State of Indiana and the Great Lakes Region related to wet weather and stormwater matters.

B.2.3 Susan Ancel, EPCOR

Susan Ancel is the Director of Stormwater Strategies for EPCOR Water Services Inc. This role within EPCOR has a primary focus on the development of an Integrated Resource Plan for Stormwater management considering capital and operational risk mitigation planning and building awareness of the interrelationships between utilities, insurance, disaster response agencies and the public in preparing and responding to changing stormwater risks in the community. Prior to taking on this role Susan was the Director of Water Distribution and Transmission responsible for the planning, engineering, construction, operation and maintenance of the water distribution and water metering systems for EPCOR in Edmonton. She has also served on numerous industry committees including the Board of Directors for the Geospatial Information Technology Association (GITA) from 2001 to 2007 and was President of GITA in 2006. She currently is a member of the Board of Directors for the Canadian Water Network.

B.2.4 Yvonne Forrest, Houston Water

As Director of Houston Water, Yvonne Forrest is responsible for the operation and maintenance of City of Houston's regional water and wastewater utility systems. She also oversees Regulatory Compliance, Infrastructure Planning and Operations/Program Support. Houston is the fourth largest city in the United States and City's public water and wastewater system is one of the largest utilities within the United States. She manages a staff of over 1600 with an annual capital and operations and maintenance budget of over $657 million.

Prior to her career in public service, Ms. Forrest spent 15 years, as an engineer, in the private sector developing processes to ensure compliance with environmental regulations, permits and corporate standards. She holds a Bachelor of Science in Chemical Engineering from University of South Carolina.

B.2.5 Pinar Balci, NYC DEP

Pinar Balci is the Assistant Commissioner of the Environmental Planning and Analysis at the NYC Department of Environmental Protection. She manages the DEP's sustainability portfolio of initiatives including the NYC Green Infrastructure Program, City-wide MS4 Stormwater Management Program, and Integrated Water Management. She also provides technical and policy support to the Long-Term Control Plans and oversees Environmental Impacts Assessments of DEP's capital program. Prior to joining NYC DEP, she has held multiple management positions at the South Florida Water Management District, where she was responsible for providing policy, permitting and regulatory support to an array of Everglades Restoration and Capital Project initiatives.

B.2.6 Brent Robinson, Seattle Public Utilities

Brent Robinson is a Strategic Advisor with Seattle Public Utilities in their Drainage and Wastewater branch. Brent is a licensed professional engineer in the state of Washington, with 10 years of experience in numerical modeling and program management. Brent's career focus has been on the SPU's Combined Sewer Overflow program, characterizing program magnitude, leading project options analyses, and leading SPU's application of climate science within the program management section.

B.2.7 Joseph Kratzer, Metropolitan Water Reclamation District of Greater Chicago

Joe Kratzer has been with MWRD for 16 years and is the Managing Civil Engineer for its Stormwater Management Section. Prior to joining the MWRD in 2003, Joe worked as a consulting engineer for seven years. A licensed Professional Engineering in Illinois, Joe is also a Certified Floodplain Manager since 2010 (and a life-long Chicago White Sox fan).

B.2.8 Marc Cammarata, Philadelphia Water Department

Marc Cammarata has spent all 21 years of his professional career with the Philadelphia Water Department where he currently serves as the Deputy Water Commissioner for Planning and Environmental Services. His responsibilities include the integration, direction and management of the

Departments numerous planning efforts focused on wet weather compliance, source water protection, water quality and quantity modeling, flood mitigation, green and traditional infrastructure, stream and wetland restoration, laboratory services, and climate mitigation and adaptation. His team is leading the efforts for the City of Philadelphia's "Green City, Clean Waters" program – a 25yr, multi-billion-dollar infrastructure program integrating land-based urban sustainability goals with the goals for clean, safe, attractive and accessible rivers and streams.

B.2.9 James Rufo Hill, Seattle Public Utilities

James Rufo Hill is a Climate Science Advisor with Seattle Public Utilities. In addition to forecasting operationally for Seattle's urban drainage, wastewater, and water supply departments, he's helps the City adapt to climate impacts, from extreme heat and wildfire smoke, to snow drought and sea level rise.

B.2.10 Julia Rockwell, Philadelphia Water Department

Julia Rockwell has been with the Philadelphia Water Department since 2009. She has worked on a variety of initiatives, including the Source Water Protection Program and Capital Planning Program. In 2014, Julia transitioned to leading the development and implementation of the department's Climate Change Adaptation Program. The goal of the program is to reduce the risks and associated expenses PWD will face from the impacts of climate change by identifying and implementing effective and feasible adaptation strategies. Julia holds a bachelor's degree in Civil and Environmental Engineering from Bucknell University and a Master of Environmental Management Degree from Duke University.

B.2.11 Anna Roche, San Francisco Public Utilities

Anna M. Roche is a Project Manager with a focus on climate change for the San Francisco Public Utilities Commission. She holds a science degree and has worked in the environmental field for over 25 years. She serves as the climate change lead for the Wastewater Enterprise and is responsible for directing the development and integration of climate change planning into project development.

B.2.12 Radley Horton, Columbia University/NASA GISS, CCRUN (RISA)

Radley Horton is a Lamont Associate Research Professor at Columbia University's Lamont-Doherty Earth Observatory. His research focuses on climate extremes, tail risks, climate impacts, and adaptation. Radley was a Convening Lead Author for the Third National Climate Assessment. He currently Co-Chairs Columbia's Adaptation Initiative, and is Principal Investigator for the Columbia University-WWF ADVANCE partnership, and the NOAA-Regional Integrated Sciences and Assessments-funded Consortium for Climate Risk in the Urban Northeast. He is also the Columbia University lead for the Department of Interior-funded Northeast Climate Science Center, and is a PI on an NSF-funded Climate Change Education Partnership Project. Radley has been a Co-leader in the development of a global research agenda in support of the United Nations Environmental Program's Programme on Vulnerability, Impacts, and Adaptation (PROVIA) initiative. He serves on numerous national and international task forces and committees, including the Climate Scenarios Task Force in support of the 2018 National Climate Assessment, and frequently appears on national and international television, radio, and in print. Radley teaches in Columbia University's Sustainable Development department.

B.2.13 Franco Montalto, Drexel University

Dr. Montalto, P.E. is a designer, researcher, educator, and visionary with expertise in the conceptualization, planning, and implementation of a wide range of urban sustainability and resilience projects. Through eDesign Dynamics, the engineering firm he founded in 2002, Dr. Montalto works with a wide range of clients to design and implement innovative solutions to water infrastructure challenges in urban and urbanizing settings. As a professor and researcher at Drexel University, he develops and tests new approaches for realizing ecological, social, and economic goals in the design of the built environment, especially in the context of climate change. He is also the Director of the North American Hub of the Urban Climate Change Research Network (UCCRN).

B.2.14 Mark Maimone, CDM Smith

Dr. Maimone is a senior water resource management specialist with experience in groundwater and surface water studies; source water protection and stormwater studies; water quality studies; wetlands remediation; and mathematical modeling of ground and surface water. He is currently the project manager for CDM Smith's support of the Philadelphia Water Department in implementing their groundbreaking sustainable stormwater management program "Green City Clean Waters". He has been responsible for the development, calibration, and validation of groundwater flow and salt water intrusion models, and has designed data management systems for water resource planning.

B.2.15 Carolina Coelho Maran, Broward County

Dr. Coelho Maran is a Water Resources Engineer, with over 16 years of experience in water resources planning, management and regulation; water security, water allocation, permitting and conflict resolution; hydrologic and hydraulic modeling, decision support systems and GIS; environmental, urban and regional planning. Has been responsible for several interdisciplinary projects and research, including collaboration with International Organizations, and for writing proposals, technical and scientific reports and several articles in worldwide-recognized publications.

B.2.16 Nora Beck, Chicago Metropolitan Agency for Planning

As a Senior Planner at the Chicago Metropolitan Agency for Planning, Nora has helped to shape a regional vision for water resources in the next regional comprehensive plan, ON TO 2050. She manages a variety of projects that incorporate stormwater management and water supply planning in local plans and regional analyses. Nora received her Bachelor’s degree in Zoology and Environmental Studies from the University of Wisconsin – Madison and Master’s degree in Urban Planning from the University of Michigan.

APPENDIX C

Panel Descriptions and Composition

C.1 Plenary Panel: Setting the Stage

C.1.1 Focus and Guiding Questions

The plenary panel set the stage for the entire workshop, providing an overview of the challenges of managing extreme precipitation and urban flooding, the current state of the art of urban stormwater and wastewater planning, and the scientific and engineering questions surrounding the incorporation of climate projections and other uncertainties into the planning process. The goals for this first session were to:

- Introduce and describe the problems the workshop will address.
- Establish a common level of understanding across the group.

In addition to providing a big-picture view of the challenges of climate-informed resilience planning and the current state of the art, panelists also motivated the four themes explored in further detail in the workshop, including the opportunities and barriers to integrated planning in today's regulatory context; the technical issues associated with developing plausible climate scenarios; approaches to simulation modeling and uncertainty analysis; and the efficacy of policy levers and implementation pathways.

C.1.2 Composition of the Panel

The panel was moderated by Pedro Ribiero, C40 Cities Climate Leadership Group. The panelists were:

- Gerald Galloway, Professor of Engineering in the Department of Civil and Environmental Engineering, University of Maryland.
- Claudio Ternieden, Senior Director of Government Affairs and Strategic Partnerships at the Water Environment Federation.
- Susan Ancel, Director of Stormwater Strategies at EPCOR, a utility company based in Edmonton, Canada.
- Yvonne Forrest, Deputy Director of Houston Water.

Brief bios of panelists and moderator can be found in Appendix B.

C.2 Theme 1 Panel: Integrated Infrastructure Planning and the Current Regulatory Context

C.2.1 Focus and Guiding Questions

The Theme 1 Panel focused on the range of operational and planning objectives that stormwater and wastewater utilities are trying to achieve now and in the future. Utilities in this sector must work towards a range of different objectives at once; and policy decisions or investments to help achieve one objective may help or hinder progress towards others. Some objectives tie directly to legal or regulatory requirements, while others may emerge in response to location-specific vulnerabilities or hazards. Utilities must also recognize that public agencies, local stakeholders, and community members may have differing preferences about the relative importance of objectives, and need to be able to account for these perspectives when resolving tradeoffs and making decisions.

Guiding questions for this panel discussion included:

- What are the necessary elements of integrated stormwater and wastewater infrastructure planning to manage flows, meet water quality standards, and protect ecosystems?

- Are different objectives moving up or down the priority list in response to changing conditions, either at present, or projected into the future?
- How should economic impacts be assessed to support an integrated planning process?
- How might utilities incorporate differing preferences and perspectives and resolve tradeoffs when making capital or operational decisions?

C.2.2 Composition of the Panel

The panel was moderated by Alan Cohn, NYC DEP. The panelists were:

- Pinar Balci, Assistant Commissioner at NYC DEP.
- Brent Robinson, Strategic Advisor for Seattle Public Utilities.
- Joseph Kratzer, Managing Civil Engineer at the Metropolitan Water Reclamation District of Greater Chicago.
- Marc Cammerata, Deputy Water Commissioner for Planning at the Philadelphia Water Department.

Brief bios of panelists and moderator can be found in Appendix B.

C.3 Theme 2 Panel: Climate Resilience and Scenario Inputs

C.3.1 Focus and Guiding Questions

The Theme 2 Panel focused on how historical and climate-projected rainfall estimates are being used to inform planning and decision making. Panelists discussed: the state-of-the-art regarding how hydrologic uncertainties are being represented and applied; approaches to understand and characterize extreme precipitation given a changing climate; and key questions utilities still need to address to establish best practices for incorporating climate and hydrology uncertainty into near-and long-term plans.

Guiding questions for this panel included:

- What approaches to hydrologic uncertainty are currently being used (e.g., historical analogs, downscaled time series, modified Intensity Duration Frequency (IDF) curves), and what are their strengths and weaknesses?
- What lessons can be learned from the use of climate scenarios for water supply planning?
- What existing inputs and approaches are available for projecting future rainfall patterns, including extreme events, and land use changes?
- What are the key gaps and what tools are needed to resolve them?

C.3.2 Composition of the Panel

The panel was moderated by Adam Parris, Office for Resilience and Recovery, Office of the Mayor, New York City. The panelists were:

- James Rufo Hill, Climate Adaptation Specialist for Seattle Public Utilities.
- Julia Rockwell, Climate Change Adaptation Program Manager at the Philadelphia Water Department.
- Anna Roche, Climate Change and Special Projects Manager for the San Francisco Public Utility. Commission
- Radley Horton, Research Professor at Columbia University; PI of CCRUN RISA.

Brief bios of panelists and moderator can be found in Appendix B.

C.4 Theme 3 Panel: Continuum of Modeling Tools and Model Integration

C.4.1 Focus and Guiding Questions

The Theme 3 Panel focused on providing an introduction to H&H (hydrologic and hydraulic) modeling, and discussing new and innovative approaches to develop and apply simulation models, in isolation or combination, to support climate-resilient storm and wastewater planning. Modeling tools discussed were those intended to inform the planning goals discussed in Theme 1 and include representations of water flows (e.g., hydrologic and hydraulic models), natural or engineered systems, and/or human systems, as well as their interrelationships. Panelists discussed a range of approaches, from "rule of thumb" guidelines to high-resolution and/or integrated simulation modeling suites.

Guiding questions for this panel included:

- What are the advantages and limitations of modeling and planning/design tools, ranging from traditional engineering approaches to more sophisticated simulation models?
- How should utilities consider and resolve the tradeoffs between model resolution and cost/computational intensity (e.g., 1D vs. 2D analysis to inform urban flood planning)?
- What are the key data requirements for building and calibrating effective simulation models, and where are gaps in data availability most evident or challenging?
- What does model integration actually mean in practice?

C.4.2 Composition of the Panel

The panel was moderated by Jordan Fischbach, Senior Policy Researcher at the RAND Corporation. The panelists were:

- Franco Montalto, Associate Professor at Drexel University.
- Mark Maimone, Senior Vice President at CDM Smith.
- Carolina Coelho Maran, Water Resources Manager for Broward County.
- Nora Beck, Senior Planner for the Chicago Metropolitan Agency for Planning.

Brief bios of panelists and moderator can be found in Appendix B.

C.5 Theme 4 Breakout Groups: Policy Levers and Implementation

C.5.1 Focus and Guiding Questions

The Theme 4 session was structured to around four break-out groups to enable workshop participants to discuss in a smaller group setting the potential next steps and develop priorities moving forward. A facilitator and note taker were chosen for each group.

Guiding questions/prompts for the groups included:

- What do you consider the top three priorities to emerge from the workshop? Consider the following topics/categories:
    - Research questions.
    - Data collection and analysis.
    - Modeling and the treatment of uncertainty.
    - Implementation of changes in operations.
    - Launch new initiatives.
    - Regulatory/policy opportunities and barriers.
- For each of your priorities, what might be the key enablers or constraints that would determine whether progress could be made within the next 12 to 24 months?
- Which of these priorities might be top candidates for collaboration among the utilities?

C.5.2 Group Facilitators and Participants

- Group 1
  - Facilitator: Katy Lackey.
  - Participants: Pinar Balci, Nora Beck, Yvonne Forrest, Brent Robinson, John Brock, Peter Adams, Kristin Baja, Marisa Flores-Gonzales, Jennifer Cherrier, Emmet Owens.
- Group 2
  - Facilitator: Tom Kimes.
  - Participants: Franco Montalto, Marc Cammarata, Larry Beckardt, Gerry Galloway, Adam Parris, Valerie Washington, Kevin Hanley, Nancy Beller-Simms, Harry Zhang, Rachel Chisolm, Wing Tam.
- Group 3
  - Facilitator: Nick Bonard.
  - Participants: Alan Cohn, Anna Roche, Mark Maimone, Julia Rockwell, Susan Ancel, Nate Kimball, Bernice Risenzweig, Ellen Mecray, Tirusew Asefa, Pedro Riveiro, Jordan Fischbach.
- Group 4
  - Facilitator: Kristen Acock.
  - Participants: Joseph Kratzer, Carolina Maran, James Rufo-Hill, Claudio Ternieden, Amanda Ikert, Krista Romita Grocholski, Erin Morey, Caitlin Simpson, Charles Olsen, Equisha Glenn.

C.3.1 Summary of Observations from the Groups

C.3.1.1 Group 1: Facilitated by Katy Lackey, US Water Alliance

The group discussed all of the priorities, how they are all complicated and interconnected and we need more work and information on all of them. Three priorities emerged:

- Modeling and treating uncertainty
  - Enablers
    - More and better data, but also better visualization of that data.
    - To utilize the data in models, problems statements need to be clarified.
    - Need to build consensus on goals for models.
    - Better communication on what drives uncertainties.
  - Constraints
    - Lack of data to go into the models (i.e., some cities don't have sewer systems mapped out).
    - Analysis paralysis.
    - Diminishing return on investments for utilities. What are they getting out of the modeling?
- Communicating uncertainty, risk, and translating it into action. Identified three parties to the conversation: climate and H&H modelers, utilities and local government officials, customers.
  - Enablers
    - Visualize data and uncertainty.
    - Pictures and maps.

    - Training scientists to talk to different constituents.
    - Developing common risk-based language.
    - Sharing in risk ownership. For example: "The numbers may be uncertain, but here is what they mean and how we are using them. They will change and this is how we will manage that."
    - Using extreme events and impacts as an example of why all of this is important.
    - Important to not only go through leadership in your utility, but also have elected officials as supporters.
  - Constraints
    - Jargon in each technical area in communicating with stakeholders and other constituents.
    - Not having a plan when numbers from analyses inevitably change as refinements are made or better data are found.
    - Lack of capacity to understand what risk really means.
- Implementation
  - Enablers
    - Launch new initiatives, framing in a way that makes clear the benefits for the community.
    - Create new regulations (e.g., local laws, standards and building codes) aligned with initiatives.
    - Need for multi-criteria analyses and a system-wide perspective.
    - High-profile disasters can provide an opportunity to propel new initiatives forward.
    - Modeling and communication.
  - Constraints
    - Regulatory barriers such as limiting issuance of permits that account for model uncertainty.
    - Models and uncertainty.
    - Time, resources, and funding which become particular challenges when trying to go above and beyond the traditional level of service. How to manage this with other capital costs facing a utility?
    - Operational discomfort within the utility.

The group also talked about interactions and coordination among these priorities. These include:

- Risk of failure as a barrier to collaboration.
- Sensors and other new technologies.
- Collaboration on modeling approaches which could save time and resources by helping other communities learn how to approach problems.
- Opportunities for larger cities to advise and translate for smaller communities who lack expertise and funding.
- Strengthening relationships between universities and utilities.

C.3.1.2 Group 2: Facilitated by Tom Kimes, Kansas City Water

The group agreed that research, funding, and equity are foundational to all priorities. Specifically, the group focused on two priorities: data and modeling, and regulatory and policy opportunities.

- Data and modeling
    - Enablers
        - Climate modeling is an opportunity, not a constraint, even though model skill is still evolving.
        - Scenario planning can help utilities and the public better understand tipping points and thresholds.
    - Constraints
        - Lack of connection to decision making.
        - Difficulty communicating uncertainties.
        - Public health impacts are not necessarily factored into the equation.
        - Reconciling the need to make decisions with the recognition that state-of-the-art methods of analysis are in flux.
- Regulatory and policy opportunities
    - Enablers
        - Forward thinking.
        - Integrated planning.
        - Integrating policy and regulation.
    - Constraints
        - Policy decided in the courts is not an effective way to make policy.
        - Difficulty communicating risk to the public.
        - Reluctance to change existing regulations and rules.
        - Lack of coordination and trust between regulators and utilities.

C.3.1.3 Group 3: Facilitated by Nicholas Bonard, District of Columbia Department of Energy and Environment

The group converged on several priorities:

- Better approaches to estimating return on investment and co-benefits.
    - The values of the agency that is implementing a project (e.g., green infrastructure) may differ from the values of the affected communities.
    - Categorizing co-benefits remains a challenge.
- Improved governance or "ownership" of flooding, especially interior flooding. Sorting out who is – or should be – doing what is problem.
- Applications of emerging technology such as cheaper sensors or artificial intelligence for designing infrastructure. For example, what if sensors were placed in GSI assets or in pipes, or if a network of cameras could provide views of flooding?
- More effective communication of flood risk as well as flood mitigation goals and metrics.

C.3.1.4 Group 4: Facilitated by Kristen Acock, City of Portland Bureau of Environmental Services

The group converged on four categories of priorities:

- Research questions and policy clarification.
  - Getting direction on the level of protection.
  - Guidance on the appropriate level of effort to put into detailed modeling versus less detailed modeling/scenario analysis.
  - Do we need to come up with IDF curves? What metric comes after this?
- Regulatory policy
  - Better understanding of availability of federal support and funding.
  - Better coordination among regulators would give communities more coordinated requirements.
  - Better coordination among policymakers within a given level of government and across levels of government.
  - More forums for discussion of regulatory policy options.
  - Coordination with businesses who might be proactive because they want more certainty.

APPENDIX D

Pre- and Post- Workshop Survey Instruments

D.1 Pre-Workshop Survey

Informed Consent for Workshop Participants

The RAND Corporation and the New York City Department of Environmental Protection are organizing the "Climate-Resilient Planning for Urban Stormwater and Wastewater Utilities Workshop" with the Water Utility Climate Alliance and support from The Water Research Foundation. The goal of the workshop is to bring together technical experts from local utilities and agencies to exchange ideas, discuss best practices, successes, and lessons learned regarding planning for extreme events and climate change in stormwater and wastewater management. We are asking you to fill out this survey to learn about your views of stormwater and wastewater management and the materials presented in the workshop.

RAND will use the information you provide for research purposes only. We will not disclose your identity or information that would identify you to anyone outside of the RAND staff working on this project without your permission, except as required by law. Taking part in this survey is voluntary. You should feel free to skip any questions that you prefer not to answer.

Whom to Contact About This Research:

If you have questions about your rights as a research participant or need to report a research-related injury or concern, you can contact RAND's Human Subjects Protection Committee toll-free at (866) 697-5620 or by emailing hspcinfo@rand.org.

You may also contact the Principal Investigator, Dr. Debra Knopman, RAND Corporation, tel. 703-413-1100, ext. 5667, or via email at Knopman@rand.org.

Please print your name:

____

We will be using your name to assign an ID number immediately after this session. Once we do this, this page with your name will be detached and discarded. We will be asking for your name each time we ask you to complete the survey (before and after the workshop) so that we can match surveys. Once the data are entered, we will discard the key that matches ID numbers to names.

URBAN STORMWATER AND WASTEWATER PLANNING WORKSHOP – SURVEY 1 (PRE-WORKSHOP)

To help us prepare for the workshop, we would like to know what topics and activities you are most interested in.

	Extremely interested	Moderately interested	A little interested	Not at all interested
Identifying new methods for managing urban stormwater and wastewater	☐1	☐2	☐3	☐4
Identifying best practices for managing urban stormwater and wastewater	☐1	☐2	☐3	☐4
Sharing ideas to inform more robust urban stormwater and wastewater infrastructure strategies to meet future needs	☐1	☐2	☐3	☐4
Building capacity to implement new integrated planning methods	☐1	☐2	☐3	☐4
Identifying future climate scenarios for stormwater and wastewater planning under uncertainty	☐1	☐2	☐3	☐4
Learning about simulation modeling for evaluating cross-sectoral approaches to long-term resiliency	☐1	☐2	☐3	☐4
Learning how to integrate climate data with existing hydrology models	☐1	☐2	☐3	☐4
Learning how to address regulatory barriers to the use of climate data and integrated modeling	☐1	☐2	☐3	☐4

Please list any other topics or activities are you interested in that are not identified above.

____

____

Personally, do you think that you are well informed or not about:

	Extremely well informed	**Fairly well informed**	**Not well informed**	**Not at all informed**	**Don't know**
The likelihood of changes to stormwater or wastewater as a result of a changing climate	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
The consequences of a changing climate for stormwater or wastewater management	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
How to prepare your organization for changes to stormwater or wastewater as a result of a changing climate	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Methods for managing stormwater or wastewater under future conditions	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Planning methods that integrate climate and hydrology information	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Simulation modeling for evaluating cross-sectoral approaches to long-term resiliency	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Regulatory barriers to the use of climate data and integrated modeling	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

There are many factors that influence the effectiveness of stormwater and wastewater management efforts. Please indicate how strongly you agree or disagree with each statement below.

	Strongly agree	**Agree**	**Disagree**	**Strongly disagree**	**Don't know**
Existing regulatory frameworks support effective management of stormwater and wastewater in my region	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Uncertainty about future conditions is used to justify non-action during discussions about planning for effective management of stormwater and wastewater	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
People involved in planning for the management of stormwater and wastewater tend to remain within their networks or communities of practice	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
We need to consider new market-based instruments to improve the effectiveness of the management of stormwater and wastewater	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
We need a stormwater and wastewater management plan that integrates across the approaches of multiple municipalities	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Building consensus for a stormwater and wastewater management plan that integrates across multiple municipalities is unlikely	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Your Work and Other Personal Information

We would like to collect some background information. This information is for analytic purposes only.

How much of your professional time do you spend working on planning for the management of stormwater and wastewater?

(Check One)

☐ 1 All my time

☐ 2 A lot of my time

☐ 3 About half my time

☐ 4 Some of my time

☐ 5 Almost none of my time

What is your primary area of current professional activity? *(Check One)*

☐ 1 Director of a private or public organization

☐ 2 Technical expert (e.g., planner, natural resource manager, hydrologist, engineer) at a private or public organization

☐ 3 Representative of a non-governmental organization with a special interest or focus

☐ 4 Policy Analyst/Advisor/Researcher

5 Other – please specify ____

Are you male or female?

Male ☐ 1

Female ☐ 2

Other ☐ 3

What is the highest level of education that you have completed? *(Check One)*

☐ 1 High school or less

☐ 2 Some college or 2-year degree

☐ 3 4-year college graduate

☐ 4 More than 4-year college degree

How would you describe your race or ethnicity? *(Check all categories that apply)*

Hispanic or Latino .... ☐ 1

Alaskan Native .... ☐ 2

American Indian .... ☐ 3

Black/African American.......... ☐ 4

White/Caucasian .... ☐ 5

Asian .... ☐ 6

Pacific Islander .... ☐ 7

Another Race or Ethnicity .... ☐ 8 SPECIFY: ______________________

Don't Know .... ☐ 9

Thank you for participating.

D.2 Post-Workshop Survey

Informed Consent for Workshop Participants

The RAND Corporation and the New York City Department of Environmental Protection are organizing the “Climate-Resilient Planning for Urban Stormwater and Wastewater Utilities Workshop” with the Water Utility Climate Alliance and support from The Water Research Foundation. The goal of the workshop is to bring together technical experts from local utilities and agencies to exchange ideas, discuss best practices, successes, and lessons learned regarding planning for extreme events and climate change in stormwater and wastewater management. We are asking you to fill out this survey to learn about your views of stormwater and wastewater management and the materials presented in the workshop.

RAND will use the information you provide for research purposes only. We will not disclose your identity or information that would identify you to anyone outside of the RAND staff working on this project without your permission, except as required by law. Taking part in this survey is voluntary. You should feel free to skip any questions that you prefer not to answer.

Whom to Contact About This Research:

If you have questions about your rights as a research participant or need to report a research-related injury or concern, you can contact RAND's Human Subjects Protection Committee toll-free at (866) 697-5620 or by emailing hspcinfo@rand.org.

You may also contact the Principal Investigator, Dr. Debra Knopman, RAND Corporation, tel. 703-413-1100, ext. 5667, or via email at Knopman@rand.org.

Please print your name:

____

We will be using your name to assign an ID number immediately after this session. Once we do this, this page with your name will be detached and discarded. We will be asking for your name each time we ask you to complete the survey (before and after the workshop) so that we can match surveys. Once the data are entered, we will discard the key that matches ID numbers to names.

URBAN STORMWATER AND WASTEWATER PLANNING WORKSHOP – SURVEY 2 (POST-WORKSHOP)

	Extremely useful	Moderately useful	A little useful	Not at all useful
What is your overall evaluation of the workshop held July 16-17, 2019?	☐ 1	☐ 2	☐ 3	☐ 4
How well did we meet the main objectives of the workshop?				
To identify new methods and best practices for managing urban stormwater and wastewater while considering climate change and future uncertainties	☐ 1	☐ 2	☐ 3	☐ 4
To share ideas to inform more robust urban stormwater and wastewater infrastructure strategies to meet future needs	☐ 1	☐ 2	☐ 3	☐ 4
To build capacity to adopt and implement new integrated planning methods	☐ 1	☐ 2	☐ 3	☐ 4
How well were the workshop discussions facilitated?	☐ 1	☐ 2	☐ 3	☐ 4
How well did we capture your comments and ideas during the workshop?	☐ 1	☐ 2	☐ 3	☐ 4

Would you like to participate in an activity similar to this workshop again in the future?

Yes ☐ 1

No ☐ 2

If we missed key experts or other people who should be included in a workshop like this in the future, please list them here:

____

____

Any suggestions for improving the format or content of the workshop?

____

____

Personally, do you think that you are well informed or not about:

	Extremely well informed	Fairly well informed	Not well informed	Not at all informed	Don't know
The likelihood of changes to stormwater or wastewater as a result of a changing climate	☐1	☐2	☐3	☐4	☐5
The consequences of a changing climate for stormwater or wastewater management	☐1	☐2	☐3	☐4	☐5
How to prepare your organization for changes to stormwater or wastewater as a result of a changing climate	☐1	☐2	☐3	☐4	☐5
Methods for managing stormwater or wastewater under future conditions	☐1	☐2	☐3	☐4	☐5
Planning methods that integrate climate and hydrology information	☐1	☐2	☐3	☐4	☐5
Simulation modeling for evaluating cross-sectoral approaches to long-term resiliency	☐1	☐2	☐3	☐4	☐5
Regulatory barriers to the use of climate data and integrated modeling	☐1	☐2	☐3	☐4	☐5

There are many factors that influence the effectiveness of stormwater and wastewater management efforts. Please indicate how strongly you agree or disagree with each statement below.

	Strongly agree	Agree	Disagree	Strongly disagree	Don't know
Existing regulatory frameworks support effective management of stormwater and wastewater in my region	☐1	☐2	☐3	☐4	☐5
Uncertainty about future conditions is used to justify non-action during discussions about planning for effective management of stormwater and wastewater	☐1	☐2	☐3	☐4	☐5
People involved in planning for the management of stormwater and wastewater tend to remain within their networks or communities of practice	☐1	☐2	☐3	☐4	☐5
We need to consider new market-based instruments to improve the effectiveness of the management of stormwater and wastewater	☐1	☐2	☐3	☐4	☐5
We need a stormwater and wastewater management plan that integrates across the approaches of multiple municipalities	☐1	☐2	☐3	☐4	☐5
Building consensus for a stormwater and wastewater management plan that integrates across multiple municipalities is unlikely	☐1	☐2	☐3	☐4	☐5

Your Work and Other Personal Information

We would like to collect some background information. This information is for analytic purposes only.

How much of your professional time do you spend working on planning for the management of stormwater and wastewater?

(Check One)

☐ 1 All my time

☐ 2 A lot of my time

☐ 3 About half my time

☐ 4 Some of my time

☐ 5 Almost none of my time

What is your primary area of current professional activity?

(Check One)

☐ 1 Director of a private or public organization

☐ 2 Technical expert (e.g., planner, natural resource manager, hydrologist, engineer) at a private or public organization

☐ 3 Representative of a non-governmental organization with a special interest or focus

☐ 4 Policy Analyst/Advisor/Researcher

5 Other – please specify ____

Are you male or female? Male ☐ 1

Female ☐ 2

Other ☐ 3

What is the highest level of education that you have completed? *(Check One)*

☐ 1 High school or less

☐ 2 Some college or 2-year degree

☐ 3 4-year college graduate

☐ 4 More than 4-year college degree

How would you describe your race or ethnicity? *(Check all categories that apply)*

Hispanic or Latino .... ☐ 1

Alaskan Native........................ ☐ 2

American Indian .... ☐ 3

Black/African American........... ☐ 4

White/Caucasian .... ☐ 5

Asian .... ☐ 6

Pacific Islander .... ☐ 7

Another Race or Ethnicity .... ☐ 8 SPECIFY: ______________________

Don't Know .... ☐ 9

If you selected multiple categories above in Question 17, which one of these groups do you most strongly identify with?

Race/Ethnicity Number: _______

Don't Know .... ☐ 9

Thank you for participating.

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