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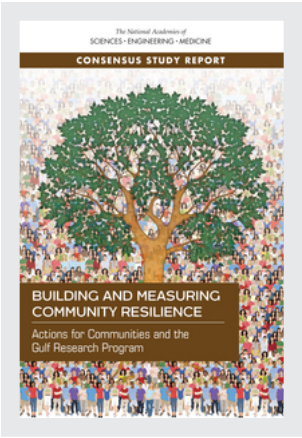

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BUILDING AND MEASURING COMMUNITY RESILIENCE

Actions for Communities and the Gulf Research Program

Committee on Measuring Community Resilience

Office of Special Projects
Policy and Global Affairs

A Consensus Study Report of

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

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This report is dedicated to the memory of Chris Elfring,
inaugural executive director of the Gulf Research Program.

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Preface

Over the last two decades, the nation has witnessed the devastation brought by major natural and human-caused disasters on our communities. Government leaders at all levels have begun to embrace the concept of resilience as a means to enhance their communities' ability to withstand and recover from such shocks. Site-specific conditions and attributes—referred to in this report as chronic stressors or pre-existing conditions—shape the intensity of the impact of an event and drive local decisions around building community resilience.

The committee's study process included visits to several places known to have made investments in resilience. These on-the-ground conversations uncovered a wide range of interpretation of resilience and revealed a set of steps that local decision makers take to identify their risks, establish achievable risk mitigation goals, and measure progress against goals that are most important to their communities. These conversations also showed that resilience takes on highly localized dimensions, and as such, community resilience must be addressed in the context of local and pre-existing conditions and circumstances. At the same time, these community discussions revealed common, uniting themes.

Given local variability in community priorities, needs, and approaches for resilience, this report recognizes that every community faces unique challenges and must tailor relevant and achievable resilience goals and means to measure progress toward those goals. Several scorecards and how-to manuals exist that purport to measure issues of resilience for all communities. They address a wide variety of resilience activities and offer insights into carrying out the activities and measuring progress, although their efficacy is unknown.

The National Academies of Sciences, Engineering, and Medicine's Gulf Research Program (GRP) has a unique opportunity to facilitate the maturation

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Building and Measuring Community Resilience: Actions for Communities and the Gulf Research Program

of resilience programs in the Gulf region through education, facilitation, and continuing research. With its sizable endowment and its 25-year timeline, the GRP is resourced to develop, implement, and measure resilience in its purview. This report lays out a framework for any community to take on its community resilience and monitor its progress; it also offers a specific approach for the GRP to do the same.

Throughout the study process, the committee received invaluable guidance and support from the GRP. This guidance and support began at our first meeting when the GRP's executive director, Ms. Chris Elfring, shared her goals and objectives for this unique, long-term program. The untimely death of Ms. Elfring in 2018 was not only a blow to the program itself, but also a significant loss to all those who knew her and profited by her wisdom. The committee has dedicated this report to her memory.

Finally, the committee owes much to the untiring efforts of Dr. Lauren Alexander Augustine, director of the Office of Special Projects and the Resilient America Program; Dr. Charlene Milliken, the study director; and Dr. Maggie Esch, research associate. Their collective intellectual acumen, organizational skills, writing abilities, collaborative temperament, and willingness to put in exceptionally long hours brought the report together and kept us focused on our mission.

Adm. Thad W. Allen, co-chair
Dr. Gerald E. Galloway, Jr., co-chair

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Acknowledgments

For the past 10 years, community resilience has been a growing theme in the national dialogue. Resilience-related research, programs, and other efforts have explored resilience across a range of scales (from the individual through global levels) and topics (from infrastructure to ecosystems to human health). Yet, communities continue to grapple with ways to measure how resilient they are now and how to track progress toward their resilience goals. To better understand the current state of resilience measurement science and practice, the committee assessed 33 resilience measurement efforts. In addition to drawing from its own expertise, the committee conferred with community stakeholders and experts, who provided invaluable information to help the committee better understand how measurement work is advancing across the United States and provided insights into how communities at the local, state, and regional levels are taking action toward resilience.

The Committee on Measuring Community Resilience gratefully acknowledges all of the local stakeholders who met with the committee to discuss resilience in their communities. The committee warmly thanks everyone who contributed their expertise, insights, and wisdom to this study, with a special thanks to:

David Abramson, Emily Accamando, Lisa Adler, Brent Anderson, Laura Armstrong, Sarah Babcock, Chuck Barney, Tom Barry, Jainey Bavishki, Nancy Beers, Sanjaya Bhatia, Nathan Bird, Garcia Bodley, Andrew Brenner, Michell Brown, Kelly Butler, Charmaine Caccioppi, Jeffrey Carney, Laurence Carter, Samuel Carter, Tommy Carver, Andrew Castaldi, Stephen Cauffman, Maretta Champagne, Brandy Christian, Craig Colten, Austin Coomer, Mac Cowand, Robert Davis, Joshua DeFlorio, Bailey DeRouen, Frank Duke, Michael Dunaway, Projjal Dutta, Jeffrey Elder, Norm Eng, Lynn Englum, Ron Erickson Sr., Sandy

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The committee also thanks the study sponsor, the Gulf Research Program, for its support and patience as the committee tackled the charges set out in the Statement of Task.

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Acknowledgment of Reviewers

This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following individuals for their review of this report: Tabia Henry Akintobi, Morehouse School of Medicine; Bilal Ayyub, University of Maryland; Philip Berke, Texas A&M University; Scott Hemmerling, The Water Institute of the Gulf; Ronald Kessler, Harvard Medical School; Marty Matlock, University of Arkansas; Michelle Meyer, Louisiana State University; Deb Niemeier, University of California, Davis; Susan Scrimshaw, Tufts University; and William Solecki, University of New York.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report nor did they see the final draft before its release. The review of this report was overseen by Robin McGuire, Lettis Consultants International, Inc. He was responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

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Summary

The frequency and severity of disasters over the last few decades have presented unprecedented challenges for communities across the United States. In 2005, Hurricane Katrina exposed the complexity and breadth of a deadly combination of existing community stressors, aging infrastructure, and a powerful natural hazard. In many ways, the devastation of Hurricane Katrina was a turning point for understanding and managing disasters, as well as related plan making and policy formulation (Olshansky and Johnson, 2010). It brought the phrase "community resilience" into the lexicon of disaster management (Cutter, et al., 2006; Cutter and Emrich, 2006; Fothergill and Peek, 2015; Fussell, Sastry, and VanLandingham, 2010; Laska and Morrow, 2006; Levine, Esnard, and Sapat, 2007; Weber and Peek, 2012).

In 2012, the National Research Council report *Disaster Resilience: A National Imperative* defined resilience as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (NRC, 2012, 1) and recommended measuring progress toward resilience. A multitude of frameworks, assessment tools, resilience indexes, and resilience programs have emerged since then to capture progress in and measurement of increased community resilience. The efforts are diverse and range from large, international programs (e.g., 100 Resilient Cities—Pioneered by the Rockefeller Foundation, United Nations Office for Disaster Risk Reduction Making Cities Resilient Campaign, Z Zurich Foundation) to national programs (e.g., the National Academies' Resilient America Program, RISE Resilience Innovations, ICLEI, the National Institute of Standards and Technology's Community Resilience Program), and local efforts (e.g., Sustainable Seattle, Charleston Resilience Network).

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Building and Measuring Community Resilience: Actions for Communities and the Gulf Research Program

BOX S-1
Statement of Task

The committee will produce a consensus report presenting effective options for measuring resilience at the community level. Specifically, the committee will:

1. Examine measurement work under way by organizations such as the Z Zurich Foundation, 100 Resilient Cities—Pioneered by The Rockefeller Foundation, The Nature Conservancy, National Oceanic and Atmospheric Administration, National Institute of Standards and Technology, Federal Emergency Management Agency, federal cross-agency groups, or others, and:
   a. Comment on their different approaches,
   b. Identify common challenges or research needs related to measuring resilience, and
   c. Discuss applications for these or other approaches at the community level;
2. Document similarities and differences among approaches used by federal agencies and other organizations to measure resilience;
3. Describe the methodologies used for quantitative and qualitative data collection and data analysis;
4. Confer with community leaders and decision makers who have implemented resilience measures about the approaches, challenges, or successes they have encountered in measuring resilience in their respective communities; and
5. Provide findings and recommendations on common approaches to measuring resilience that have shown success, ways to overcome the challenges of measuring resilience, and key issues for future programs to consider in measuring the resilience of a community.

In 2010, the Deepwater Horizon oil spill and explosion occurred in the same region as Hurricane Katrina had 5 years prior. Deepwater Horizon renewed questions about resilience in the states and communities of the Gulf of Mexico. In November 2013, the National Academy of Sciences received $500 million in settlement funds from the Deepwater Horizon criminal cases to ". . . improve understanding of the region's interconnecting human, environmental, and energy systems and foster . . . benefit[s] [for] Gulf communities, ecosystems, and the nation" (NASEM, 2017a) over a 30-year time period. The National Academy of Sciences created the Gulf Research Program (GRP)[1] to carry out this mission. In 2016, the GRP requested a report to present "effective options for measuring resilience at the community level" (see Statement of Task, Box S-1).

[1] For information about the Gulf Research Program: http://www.nationalacademies.org/gulf/index.html.

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Building and Measuring Community Resilience: Actions for Communities and the Gulf Research Program

In addressing the Statement of Task, this report summarizes the existing portfolio of relevant or related resilience measurement efforts (Chapter 2) and notes gaps and challenges associated with them. It describes how some communities build and measure resilience (Chapter 3) and offers four key actions that communities could take to build and measure their resilience in order to address gaps identified in current community resilience measurement efforts (Chapter 4). Finally, the report provides recommendations to the GRP to build and measure resilience in the Gulf of Mexico region (Chapter 5).

Based on the existing literature and research efforts, community meetings, and examination of other resilience programs, the committee found that no single measurement of resilience exists for all elements of resilience for all communities (Finding 3.2). The report also highlights several actions needed to build and measure community resilience:

- Utilize community participation and engagement at the outset of community resilience building and measurement efforts to engender buy-in around resilience priorities, goals, and leadership;
- Design and measure resilience around multiple dimensions of a community, for example, the natural, built, financial, human, social, and political "capitals" of resilience;
- Use measures to track progress and in decision making and ensure that the data collected, integrated, or synthesized are relatable and usable for decision making; and
- Incentivize measuring resilience by expressing multiple benefits gained from single investments.

And the report highlights one action specifically for the GRP:

- Develop a major, coordinated initiative around community resilience in communities across the Gulf region that includes longitudinal resilience research and a learning collaborative among Gulf region communities.

EVALUATION OF EXISTING RESILIENCE MEASUREMENT EFFORTS

The committee examined a sample of 33 resilience measurement efforts in describing the current state of scholarship and practice of community resilience measurement (see Box S-1, tasks 1, 2, and 3). The large number of available measurement tools and approaches underscores the fact that no single measurement tool fits the resilience measurement needs of all communities.

A defining characteristic of community resilience across most of the tools is that resilience includes multiple dimensions (Finding 3.5), which are broadly encompassed by six assets (or "capitals") across a community: natural, built,

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financial, human, social, and political. Few of the measurement efforts developed since the publication of the National Research Council's *Disaster Resilience: A National Imperative* consider all six of the commonly used community capitals, and few measurement efforts have been applied more than once in the same community or in more than one community. These findings suggest that resilience measurement science and practice are not yet mature, and many of the existing methods still need validation.

GROUND TRUTHING HOW COMMUNITIES MEASURE RESILIENCE

The committee conferred with diverse stakeholders in eight communities with demonstrated disaster or resilience experience (Box S-1, task 4), who came from local government, the private sector, the nonprofit sector, research centers, and academic institutions. The community stakeholder meetings elucidated how resilience measurement advances at the community scale and revealed experiences related to the approaches, challenges, and successes that communities encounter in measuring resilience. The community site visits and meetings reflected knowledge gaps, research directions, and opportunities that could pave the way for new approaches to realize more resilient communities.

The eight communities with which the committee conferred were New Orleans and Baton Rouge, Louisiana; Gulfport and Waveland, Mississippi; New York, New York; Minot, North Dakota; and Rapid City and Pine Ridge Reservation, South Dakota, representing a diversity of community perspectives in terms of hazards and risk profiles, demographic and socioeconomic profiles, geographic location, and population size. The committee also considered the experiences of additional communities, specifically, places that participated in national resilience-building efforts through the National Institute of Standards and Technology's Community Resilience Program and the National Academy of Sciences' Resilient America Program: Boulder County, Colorado; Cedar Rapids, Iowa; Charleston, South Carolina; Central Puget Sound region, Washington; and Tulsa, Oklahoma. From these site visits and investigations, common themes emerged.

1. Despite the range of readily available resilience measurement frameworks and tools, these communities are not explicitly measuring resilience (Finding 3.1), in part because no single tool among the myriad resilience measurement tools fits all communities (Finding 3.2), leaving local decision makers unsure of which, if any, of the tools to use.
2. Every community visited by the committee collects data and tracks a variety of community indicators relevant to resilience, but data or information collected for disparate purposes are often incompatible, which presents challenges in using common measures across sectors (Finding 3.3).

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3. All of the communities acknowledged that resilience encompasses much more than disaster management and they supported resilience approaches across multiple dimensions or capitals (Finding 3.5) to capture the fullness of community resilience issues.
4. The communities visited stressed that community engagement and buy-in across diverse stakeholders and sectors are critical to community resilience to help community stakeholders coalesce around goals, priorities, leadership, and other desired outcomes (Finding 3.4).

FOR COMMUNITIES: ACTIONS FOR BUILDING AND MEASURING COMMUNITY RESILIENCE

The volume of resilience measurement approaches and the paucity of actual use of those tools (Finding 3.1) suggest a gap between research and the implementation of resilience measurement. Based on a review of the resilience measurement literature and research, as well as the feedback from communities, the committee identified four key actions for building and measuring community resilience to bridge this gap. Key actions that communities could take to build and measure their resilience include: (1) building community engagement and buy-in to develop resilience goals and priorities; (2) accounting for the multiple dimensions of a community—natural, built, social, financial, human, and political—to identify resilience needs and challenges and develop resilience goals; (3) linking community resilience measurement to decision making; and (4) creating incentives for measuring resilience through actions that provide multiple benefits. From these actions, the committee offers communities four recommendations for tracking and measuring community resilience efforts.

Recommendation 1: Communities should use community participation and engagement at the outset of their resilience building and measurement efforts. The process of participation helps communities develop resilience goals and priorities and generate community buy-in for those goals. Setting goals and priorities is necessary before any measurement activities can take place, as they provide the basis against which a community can track its progress and gauge its success. Community engagement is important in developing feasible goals and setting realistic priorities (NIST, 2016). It can also nurture and identify leaders or champions within the community. The Rockefeller Foundation's 100 Resilient Cities initiative, for example, places such strong emphasis on leadership in community resilience that each participating city has a full-time chief resilience officer to carry out the resilience efforts (Salkin, 2014).

Recommendation 2: Communities should design and measure resilience around multiple dimensions of a community. Community dimensions are captured by the six capitals (i.e., natural, built, social, financial, human, and

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political), which provide a structure for setting community resilience goals and a reference for measuring progress toward those goals.

Measuring or collecting data across multiple sectors can be challenging. There are challenges of limited access to appropriate data, uncertainty about how to start or conduct resilience measurement, and incompatible data across the different sectors and capitals (Finding 3.3). But there are ways to overcome these challenges and options to better integrate information across this variety of existing data sources and sectors. For example, many federal government programs in their application process require estimated indicators of success or desired outcomes (e.g., the Federal Emergency Management Agency's Hazard Mitigation Grant Program, Individuals and Households Program, and Public Assistance grant program; the Department of Housing and Urban Development's Community Development Block Grants; and the Small Business Administration's Disaster Loan Assistance). Criteria and information gathered in these application processes could also be used in a community resilience function and these outcomes could be aligned with resilience goals or priorities.

Recommendation 3: Communities should ensure that the data collected, integrated, or synthesized for community resilience are relatable and usable for decision making. The data collected, integrated, or synthesized need to be relatable, usable, and ultimately *used* to make decisions about public sector budgets and public-private financing, to gauge the efficacy or progress of resilience goals, or to inform policy formulation and implementation.

Recommendation 4: Communities should incentivize the measurement of resilience. Community resilience investments can include milestones and yield multiple benefits that are trackable along and across the relevant community capitals. Investments reflect choices and tradeoffs that account for a range of dynamic stressors and short- and long-term gains, and those gains can be tracked along or across multiple sectors (Finding 4.2). Community resilience measurement needs to include a range of downstream or cascading impacts of investment choices in order to capture the broadest range of multiple benefits. Valuation models and financial tools like green, resilience, or catastrophe bonds have been shown to support resilience measurement (Finding 4.3), and measuring the multiple benefits of community resilience investments can be connected to existing financial and insurance structures because these structures require and incentivize quantitative measures of resilience (Finding 4.4).

FOR THE GULF RESEARCH PROGRAM: WAYS FORWARD FOR BUILDING AND MEASURING COMMUNITY RESILIENCE IN THE GULF REGION

The committee's task was to provide findings and recommendations on common approaches and "key issues for future programs to consider in measuring the

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resilience of a community" (see Box S-1). The committee interpreted this charge as referring to future programs that the GRP would administer. The GRP has a $500 million endowment, a remaining 25-year timeline, and a mandate to effect change in the Gulf region. Thus, it has the resources, time, and mission to effect positive change in the resilience of the communities impacted by Deepwater Horizon over the next quarter century.

Recommendation 5: The Gulf Research Program should develop a major, coordinated initiative around building or enhancing community resilience in communities across the Gulf region. The basic structure of a GRP community resilience initiative should include multiple communities, capture and document community resilience strategies and measurements, foster interactions across and among GRP communities through a resilience learning collaborative, and implement longitudinal research that includes systematic analysis and integration of data from various sources.

A GRP Framework for Community Resilience

The GRP community resilience initiative needs to account for community-level differences, with each community taking different approaches, identifying different priorities, and requiring different types of resources.

Recommendation 6: For each community in the Gulf Research Program community resilience initiative, the GRP should develop and employ a community resilience framework that includes: (1) community engagement to engender buy-in around resilience priorities, goals, and leadership; (2) resilience across multiple community capitals; (3) measures and ways to track progress that are useful to decision makers; and (4) investments in resilience that result in multiple benefits.

The GRP should consider a few specific actions in implementing a community resilience framework:

- *Action:* In each of the GRP communities, the GRP should engage diverse stakeholders to build community buy-in around community resilience goals or priorities and recruit local leaders and champions for resilience efforts. The GRP should expect the community engagement process to take months or even years.
- *Action:* As the GRP collaborates with communities to build community resilience, it should explicitly include as many of the community capitals as possible to capture how communities conceive their resilience priorities, approaches, investments, and assessments.
- *Action:* The GRP should be deliberate in bringing researchers and decision makers together in the community resilience process.

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- *Action:* The GRP should guide short-term investments that will yield positive long-term benefits across multiple capitals.

Learning Collaborative for Resilience

Opportunities are scarce for communities to come together to exchange ideas and solutions for resilience building and measurement although every community has a challenge, strategy, approach, or lesson to share or one that it wants to learn. The learning collaborative concept deals with community resilience at the regional scale, engendering community-to-community learning across the Gulf region.

Recommendation 7: The Gulf Research Program should create, finance, and maintain a resilience learning collaborative for diverse stakeholders to exchange information about lessons learned, approaches, challenges, and successes in their respective and collective work to advance community resilience in the Gulf region.

The collaborative participants should include government (local, state, federal levels), industry, academia, nonprofits, and other organizations working on resilience issues in the states of the Gulf of Mexico. The GRP would play a convening role for the communities involved in the GRP community resilience program and for other groups that also received funds from settlements from the Deepwater Horizon explosion and oil spill. A learning collaborative would advance the science, meaning, and utility of resilience measurement. The GRP and the National Academies would stand to benefit from this approach, as well. The GRP could emerge as a central organization on resilience among Deepwater Horizon funding programs, states, and communities of the Gulf region. The GRP could also gain and document understanding of successful activities in the region. The resilience learning collaborative would support the broader GRP mission in supporting research activities and publishing results and publications that address needs of the Gulf region.

The GRP should consider these actions for the resilience learning collaborative:

- *Action:* The GRP should organize opportunities for information exchanges among the communities that participate in its community resilience initiative in order to facilitate collaborative learning, capacity building among stakeholders, and training and mentoring, including a focus on measures of resilience.
- *Action:* The GRP should confer with other recipients of settlement funds from the Deepwater Horizon explosion and oil spill and/or organizations active in community resilience about collaborative efforts on common program elements.

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Longitudinal Research

Long-term, periodic, comprehensive resilience assessment remains an unmet need (NASEM, 2017b). Longitudinal research connects communities and research institutions across the Gulf region, as well as academic and governmental research facilities in the Gulf and beyond. A new kind of research is needed that: (1) can address the dynamic state of communities and their changes in risk and resilience over time, and (2) can link information or data from disparate programs with each other and to community resilience priorities, to ultimately (3) link research, data, and information with decision making. While the communities would initially be located across the Gulf states, the effort would include experts and researchers from outside of the Gulf region.

Recommendation 8: The Gulf Research Program should implement longitudinal research associated with its community resilience program.

The GRP should consider these actions in implementing longitudinal research:

- *Action:* The GRP should identify, collect, and maintain data that can be used to effectively monitor the changes in regional and community resilience and assess why these changes are occurring.
- *Action:* The GRP should proceed with investing, developing, and designing a longitudinal research program to collect, analyze, and integrate data from different sources that have relevance to community capitals, investments, priorities, and measures. Such integrated analysis should be relevant to existing budgets, policies, priorities, and investments.

OPPORTUNITY FOR ADVANCING COMMUNITY RESILIENCE

The Gulf region is a landscape ripe for advancing community resilience. Its mix of issues related to economy, ecology, and a diverse and vibrant culture combined with its exposure to the effects of social inequity and vulnerability, low health outcomes of its residents, an extractive economy, and natural hazards underscores the urgency of action. The GRP has a rare opportunity to alter the resilience trajectory of Gulf region communities through a community resilience framework, community engagement, a learning collaborative, and longitudinal, transdisciplinary studies that inform decision making. With the rigorous scientific imprimatur that is the signature of the National Academies, the GRP can use its platform of resources and a quarter century of time to effect an enduring, sustained legacy of resilience in the Gulf of Mexico and beyond.

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1

Introduction

The frequency and severity of disasters due to hurricanes, floods, tornadoes, wildfires, and other disasters in the first decades of the 21st century have resulted in unprecedented challenges for communities in the United States. In 2005, Hurricane Katrina revealed the complexity and breadth of how existing community stressors and infrastructure could combine with a powerful natural hazard to result in massive displacement, protracted recovery, unprecedented property losses, extensive human suffering, disproportionate impacts on the poor and disadvantaged, and worst of all, a high death toll (Blaze and Schwalb, 2009; Elliott and Pais, 2006; Groen and Polivka, 2010; Hori, Schafer, and Bowman, 2009; Kessler et al., 2008; McIntosh, 2008; Mortensen, Wilson, and Ho, 2009; Paxson and Rouse, 2008; Stringfield, 2010; Turnham et al., 2011). In many ways, the devastation of Hurricane Katrina was a turning point for understanding and managing disasters and related plan making and policy formulation (Olshansky and Johnson, 2010). It also brought the phrase "community resilience" into the lexicon of disaster management (Cutter et al., 2006; Cutter and Emrich, 2006; Fothergill and Peek, 2015; Fussell, Sastry, and VanLandingham, 2010; Laska and Morrow, 2006; Levine, Esnard, and Sapat, 2007; Weber and Peek, 2012).

The National Research Council's 2012 report *Disaster Resilience: A National Imperative* defined resilience as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (NRC, 2012, 1; for a list of key terms used in this report, see Box 1-1). The 2012 report laid out six broad tenets for building national resilience to disasters:

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1. "Understanding, managing, and reducing disaster risks" (p. 3);
2. "Demonstrating that community investments in resilience will yield measurable short- and long-term benefits that balance or exceed the costs" (pp. 3-4);
3. Measuring progress toward resilience, including potentially developing a single, uniform resilience "scorecard" (pp. 4-5);
4. "Building local capacity and accelerating progress," or resilience "from the bottom up" (pp. 5-6);
5. Harnessing the governance, policy, and resource landscape, or "top-down" resilience (pp. 6-7); and ultimately,
6. Linking communities and governments at all levels to effectively guide national resilience (pp. 7-8).

Measuring progress toward resilience, the third tenet, is the focus of this report. Measurement helps communities set priorities, establish community-resilience baselines, and monitor change over time (NRC, 2012).

BOX 1-1
Definition of Key Terms Used in this Report

Community: a geographically defined collection of people, at a subnational and substate level of jurisdiction.

Community resilience: community capabilities that buffer it from or support effective responses to disasters (from Wells et al., 2013, 1172).

Community resilience measurement effort: the breadth of activities, products, tools, and frameworks that purport to measure or support measurement of community resilience. This encompasses current attempts to: 1) operationalize and assess a specific resilience construct; 2) provide guidance to communities on indicators or components of a community that could be measured locally; 3) promote checklists or scorecards that centrally assemble indicators or subjects associated with community resilience; or 4) encourage the use of specific databases, analytical methods, or tools for communities' use in measuring.

Disaster risk: the potential for adverse effects from the occurrence of a particular hazardous event, which is derived from the combination of physical hazards, the exposure, and vulnerabilities (from NRC, 2012, 27).

Measurement: the act of assessing an object, event, or place using a reasonable and accepted standard measure (or metric) in order to compare the object, event, or place to itself at another time or in another condition, or to another object, event, or place.

Resilience: "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (from NRC, 2012, 1).

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THE CURRENT COMMUNITY RESILIENCE LANDSCAPE

The community-level resilience landscape has expanded in the United States since the publication of the NRC 2012 report *Disaster Resilience: A National Imperative*, including resilience efforts at the national, state, regional, and community levels. For the purposes of the present report, a community is a geographically defined collection of people at a subnational and substate level of jurisdiction. Included in that could be regions such as a metropolitan statistical area; rural villages or townships sharing similar environmental, cultural, or political ties; politically bounded places such as counties, cities, water districts, or wards within cities; or culturally defined places such as neighborhoods or street blocks that are greater than an individual household, parcel, or built project. Community resilience encompasses "community capabilities that buffer it from or support effective responses to disasters" (Wells et al., 2013, 1172).

National efforts that promote local changes in community resilience knowledge and practice include the 100 Resilient Cities—Pioneered by The Rockefeller Foundation; the National Academy of Sciences' Resilient America Program; city-to-city networks such as the Urban Sustainability Directors Network, ICLEI-Local Governments for Sustainability, and C40; and professional associations such as the National Hazard Mitigation Association, the American Society of Civil Engineers, the National Association of Climate Resilience Planners, and the American Planning Association. A number of federal and state investments and policies have been launched to expand local resilience capacity, including the National Institute of Standards and Technology Community Resilience Planning Guide; the U.S. Department of Housing and Urban Development programs Rebuild by Design and National Disaster Resilience Competition; the National Oceanic and Atmospheric Administration Coastal Resilience Grants Program; Federal Emergency Management Agency Hazard Mitigation Planning requirements and Ready.gov resources; and the U.S. Department of the Interior Tribal Resilience Program.

Many cities have or are creating resilience offices and programs (e.g., New Orleans Mayor's Office of Resilience and Sustainability, Resilient Seattle, City of Minot Office of Resilience, Resilient Baton Rouge, Resilient Tulsa, City of New York Mayor's Office of Recovery and Resiliency), and many regions are organizing around resilience and leveraging resources and partnerships (e.g., the Southeast Florida Climate Change Compact, the San Francisco Bay Area Planning and Urban Research Association, Boulder County Collaborative, California's Alliance of Regional Collaboratives for Climate Adaptation, King County-Cities Climate Collaboration, Association of Bay Area Governments).

This broader landscape of activity raises questions about how or whether resilience has increased, whether investments are providing adequate returns, and how decision makers can begin to understand the impact that hazard mitigation, climate adaptation, and other resilience actions are having across numerous areas of community wellbeing.

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SHOCKS AND STRESSORS

Disruptive events are often characterized as "shocks" or "stressors." Shocks are usually events that occur over a short period of time that negatively impact people's well-being, assets, safety, livelihoods, and ability to endure future shocks. Stressors, in contrast, are long-term pressures that may have no clear beginning or end and that weaken the stability of a system and increase vulnerability within it (Choularton et al., 2015). Due to the timeline difference, oftentimes "acute" is ascribed to shocks and "chronic" to stressors. However, more accurately, both shocks and stressors can be acute or chronic (see Table 1-1).

The value of the process of measuring resilience lies in a community understanding the factors that affect its resilience and illuminating the presence and interdependencies of both acute and chronic shocks and stressors within the community. The process of measuring can provide community leaders and members information to help prioritize investments, allocate limited resources, and target the most effective programs and policies to mitigate the effects of shocks and stressors.

WHAT IS MEASUREMENT?

Measurement is the act of assessing an object, event, or place using a reasonable and accepted standard measure (or metric) in order to compare the object, event, or place to itself at another time, in another condition, or to another object, event, or place. Measurement can manifest in quantitative terms of numeric values, scales, or scores. Measurement can also have qualitative properties defined by nominal descriptors (e.g., yes/no, present/absent, or destroyed/functioning; rankings such as high, medium, or low; or grades A through F, as in a scorecard); visual descriptors; or textual descriptors as conveyed through observation, interviews, focus groups, or document review (Miles, Huberman, and Saldana, 1994). Qualitative measurement makes inferences about the phenomena being measured, but employs no numeric units of measurement. Qualitative properties are often used to assess underlying processes of community engagement, goal setting, capacities, or overall operation of some specific system such as infrastructure. Though measurement efforts for resilience tend to lean toward quantification, qualitative constructs and data are just as useful in depicting and measuring

TABLE 1-1 Examples of Types of Shocks and Stressors

	Shocks	Stressors
Chronic	Sea level rise, drought, land subsidence	Housing shortages; homelessness; opioid epidemic; crime
Acute	Flood, terrorist attack, hurricane, earthquake, environmental contamination	Loss of employment, loss of health care, financial collapse, massive mortgage defaults

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resilience (Maxwell et al., 2015). Sometimes quantitative and qualitative approaches can be used together to address common research questions (Creswell, 2015). For example, qualitative data might be translated into geographic information system (GIS) formats (Aitken and Kwan, 2009; Bagheri, 2014; Boschmann and Cubbon, 2014; Cope and Elwood, 2009) or into an economic model that can be used to assess the value of resilience-related projects or initiatives.

Interest in community resilience measurement is evolving steadily. In recent years, organizations have invested millions of dollars in the development and implementation of a portfolio of measurement frameworks to measure community resilience (see Chapter 2). Throughout this report, the breadth of activities, products, tools, and frameworks that purport to measure or support measurement of community resilience is referred to as community resilience measurement *efforts*. This term encompasses current scholars' and practitioners' attempts to: 1) operationalize and assess a specific resilience construct; 2) provide guidance to communities on indicators or components of a community that could be measured locally; 3) promote checklists or scorecards that centrally assemble indicators or subjects associated with community resilience; or 4) encourage the use of specific databases, analytical methods, or measurement tools for communities. This report builds on these efforts by distilling key elements that can guide community resilience and its measurement in ways that build on this foundation.

DIMENSIONS OF COMMUNITY RESILIENCE

A defining characteristic of community resilience noted in the literature and in implementation is multidimensionality (Beccari, 2016; Cutter, 2016a; NRC, 2012)—in other words, the resilience of a community encompasses all of the resources and assets available in the community. These community dimensions are also referred to as "capitals." The concept of community capitals is grounded in community development and disaster research, and basic forms of capital available in communities include natural, built (physical), financial (economic), human and cultural, social, and political (Flora and Flora, 1993; Flora et al., 2008; NIST, 2016; Ritchie and Gill, 2011).

The grouping and measurement of capitals in the context of community resilience have evolved based on improvements in empirical research and a broad-based examination of available data. An early example of measurement efforts for regional resilience (though not intended to be a measure of resilience to disasters in particular) was the Resilience Capacity Index,[1] which included 12 socio-economic variables and no indicators for physical or infrastructure capitals (Alkire and Foster, 2011). Another, the Baseline Resilience Indicators for Communities, uses six capitals—social, economic, community, institutional, housing/infrastructure, and environmental conditions—which were derived from

[1] Appendix D provides a brief description of each measurement effort mentioned in this report.

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an analysis of more than 60 variables (Cutter, Ash, and Emrich, 2014). The City Resilience Index retains these six capitals but suggests that as many as 156 variables operationalize the measuring of community resilience (Arup, 2015).

The number and quality of operational variables in the resilience measurement world vary widely (see Cutter et al., 2008; Cutter, Burton, and Emrich, 2010; Gunderson, 2010; Kulig et al., 2013; Mowbray et al., 2007; Norris et al., 2008; Rose and Krausmann, 2013; Sherrieb, Norris, and Galea, 2010). However, the following six types of community capitals (or community resilience dimensions) represent those most often used in the resilience measurement literature:

- **Natural (or environmental):** the natural resources base or environmental conditions within communities. This includes air, land, water, mineral resources, stability and health of ecosystems, natural land cover, and/or indicators of environmental quality.
- **Built (infrastructure):** the buildings and infrastructure systems within communities. This includes critical response support facilities, residential housing, schools, commercial and industrial buildings, and supporting infrastructure such as power, transportation, bridges, roads, communication, water, and waste water.
- **Financial (economic):** the totality of economic assets and livelihoods in a community. This includes income levels, personal wealth, income equality, overall employment rates, sector-specific employment, and business size and diversity.
- **Human and cultural:** demographic characteristics, knowledge, skills, health, and physical abilities of community members including language competencies, cultural symbols, and belief systems. Some specific examples are educational levels, age distributions, health insurance, access to medical and mental health services, food security, special needs populations, and access to transportation and communication services.
- **Social:** the social networks and connectivity among groups and individuals within a community. This includes levels of trust and reciprocity, political engagement, length of residence, volunteerism, religious affiliation, and community organizations and services. Also included is the feeling of belonging to and a sense of place about the community.
- **Political (institutional or governance):** access to resources and the ability/power to influence their distribution as well as the ability to engage external (to the community) entities in efforts to achieve community goals. This includes disaster insurance coverage (e.g., flood, crop), jurisdictional coordination or fragmentation, disaster experience in response and recovery, mitigation spending, and emergency management capacities.

Accounting for these six dimensions provides a more holistic view of community resilience, and the importance of each dimension to a community's ability to prepare and plan for, absorb, recover from, and more successfully adapt to

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adverse events is becoming more established in the literature (Bourdieu, 1986; Cutter, 2016a; NRC, 2012; Ritchie and Gill, 2011; Šlaus and Jacobs, 2011). Yet, there is no consistent grouping of the various dimensions of community resilience or of the variables within them (Béné, 2013; ODI and RMEL CoP, 2016).

WHY MEASURE COMMUNITY RESILIENCE?

All communities experience a mix of shocks and stressors. Therefore, measuring resilience can help communities (Cutter, 2016a; NRC, 2012):

- Raise awareness and garner buy-in among community stakeholders about the importance of being resilient;
- Define what resilience means within their communities;
- Establish their baseline resilience to enable them to monitor their progress toward specific goals;
- Identify their risks and prioritize their needs and goals;
- Compare the benefits of increasing resilience to its costs in order to prioritize investments;
- Allocate limited resources for their resilience-building efforts;
- Quantify desired returns associated with investments to enhance resilience or prioritize among possible investments; and/or
- Determine whether they make progress toward goals, and if so, how quickly.

In addition, effective measures or indicators can be used to improve response and recovery planning; define and prioritize mitigation efforts; and make choices related to policy, insurance pricing, and other investments. Measures can also help allocate resources: In the 2017 National Oceanic and Atmospheric Administration Coastal Resilience Grant, "measurable impact" was a key criterion for selecting grant recipients; examples of impact measures included baseline assessments, milestones or demonstrated progress toward goals, and avoided losses.

Finally, resilience measurement must be viewed within the context of historical and structural conditions such as prior stress and trauma, structural racism, government dysfunction, and shifts in demographic and economic conditions. Historical context influences what decisions can be made to mitigate and adapt to stress, prepare communities for disaster response, and help communities recover during overlapping cycles of disaster. The measurement of resilience is not complete without consideration of this historical context.

In recent years, researchers and practitioners have begun to more fully appreciate cumulative community stress—or community allostatic load—as helping to explain why some communities are able to withstand or adapt to stress and disaster more readily than others. Measurement of community allostatic load can include foundational issues such as intergenerational poverty, disenfranchisement of particular populations, or residential segregation. It also includes measurement

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of community history in responding to prior stress and the equity and effectiveness of that response (Chandra et al., 2018).

COMMUNITY RESILIENCE IN THE GULF REGION

On April 20, 2010, an explosion on the Deepwater Horizon oil rig resulted in 4.9 million barrels of oil flowing into the Gulf of Mexico. In January 2013, TransOcean and British Petroleum pleaded guilty to criminal charges related to Deepwater Horizon. In November 2013, the National Academy of Sciences received $500 million in settlement funds from the Deepwater Horizon criminal cases to be expended over 30 years to "enhance oil system safety and the protection of human health and the environment in the Gulf of Mexico region and other areas along the U.S. outer continental shelf with offshore oil and gas operations [in order to] improve understanding of the region's interconnecting human, environmental, and energy systems and foster the application of these insights to benefit Gulf communities, ecosystems, and the nation" (NASEM, 2017a). The National Academy of Sciences created the Gulf Research Program[2] (GRP) to fulfill this mission.

The GRP has a rare opportunity to alter the resilience trajectory of Gulf region communities. It has the enviable combination of time and money to effect change and shape resilience actions over the next quarter century. The complexities of economy, culture, and environment in the Gulf region align well with those of community resilience. If the GRP were to take community resilience into its programmatic portfolio, establishing its approach to measurement would be important. Furthermore, the GRP could use resilience measures to quantify the program's impact on the quality of life, safety, and resilience of the Gulf region.

In the past 15 years resilience researchers, philanthropists, and policy makers have been busy designing, testing, and evaluating how best to measure community resilience, and many of those efforts have focused on Gulf Coast communities. The fruits of that labor are ripe for consideration, adaptation, or application in Gulf region communities and the GRP's future planning for its programs. And the need to measure resilience extends beyond the Gulf. Many other regions and communities face similar or relatable environmental choices, economic pressures, and health and social challenges, and this report aims to be relevant to these places and decision makers, as well.

STATEMENT OF TASK

The GRP requested this study and charged the committee to "produce a consensus report presenting effective options for measuring resilience at the

[2] For more information about the Gulf Research Program, visit http://www.nationalacademies.org/gulf/index.html.

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community level" (see Box 1-2). The consensus study process adhered to the Federal Advisory Committee Act requirements used for consensus activities with federal sponsors to ensure the committee maintained objectivity and independence in its findings and recommendations.

The committee conferred with community leaders and decision makers about their experiences in measuring resilience. The committee conducted a set of open sessions in the forms of site visits, videoconferences, and other interactions with local experts. Through these meetings, the committee fulfilled charges 1, 2, and 4. Charges 3 and 5 were fulfilled through closed session meetings that allowed for committee discussions, deliberation, and report writing.

The committee met with community representatives from four communities in the Gulf region (Baton Rouge and New Orleans, Louisiana, and Gulfport and Waveland, Mississippi); New York, New York; Minot, North Dakota; and Rapid City and Pine Ridge, South Dakota. The committee purposefully selected these

BOX 1-2
Statement of Task

The committee will produce a consensus report presenting effective options for measuring resilience at the community level. Specifically the committee will:

1. Examine measurement work under way by organizations such as the Z Zurich Foundation, 100 Resilience Cities—Pioneered by The Rockefeller Foundation, The Nature Conservancy, National Oceanic and Atmospheric Administration, National Institute of Standards and Technology, Federal Emergency Management Agency, federal cross-agency groups, or others, and:
   a. Comment on their different approaches;
   b. Identify common challenges or research needs related to measuring resilience; and,
   c. Discuss applications for these or other approaches at the community level.
2. Document similarities and differences among approaches used by federal agencies and other organizations to measure resilience;
3. Describe the methodologies used for quantitative and qualitative data collection and data analysis;
4. Confer with community leaders and decision makers who have implemented resilience measures about the approaches, challenges, or successes they have encountered in measuring resilience in their respective communities; and,
5. Provide findings and recommendations on common approaches to measuring resilience that have shown success, ways to overcome the challenges of measuring resilience, and key issues for future programs to consider in measuring the resilience of a community.

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communities because they represented a range of community types (e.g., rural/urban, differing demographic profiles, population size) represented local and state perspectives, because of their recent disaster histories, and for their exposure to resilience measurement efforts.

ORGANIZATION AND INTENT OF THIS REPORT

This report reviews the status of resilience measurement to date and ends with recommendations for the GRP to advance resilience measurement and community resilience in communities on or near the Gulf of Mexico. This report is not a how-to manual on measuring community resilience or a compendium of resilience programs, fundamentals, or principles to successfully carry out measurement. Nor is it a collection of community resilience measures and indicators. Rather, this report presents a framework of four key actions (Chapter 4) that communities can take to build and measure resilience.

This report seeks to reach two audiences. The primary audience is the GRP, for whom this report provides GRP-specific recommendations to build and measure community resilience in the Gulf of Mexico region (Chapter 5). The secondary audience is decision makers at the community level who are interested in advancing resilience in their communities. For this audience, the report presents four community-focused recommendations (Chapter 4).

This report summarizes the existing portfolio of resilience measurement efforts (Chapter 2); provides an encapsulation of what select communities shared of their experiences in measuring resilience and identifies four common themes across communities for building resilience (Chapter 3); offers a framework based on the four common themes for communities looking to build and measure their resilience (Chapter 4); and provides recommendations to the GRP to build and measure resilience in Gulf of Mexico region (Chapter 5).

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2

Evaluation of Existing Resilience Measurement Efforts

BOX 2-1
Chapter 2 Findings

Finding 2.1 Few of the measurement efforts consider all of the six commonly used community dimensions or capitals.

Finding 2.2 Resilience measurement science and practice are not mature enough to clearly articulate which resilience measurement approach is best or works best in practice.

The community resilience movement has made significant advances over the past decade. Initiatives explicitly intended to build resilience have been promoted by organizations such as the Rockefeller Foundation, The Nature Conservancy, and the Z Zurich Foundation; by government agencies such as the National Oceanic and Atmospheric Administration, the National Institute of Standards and Technology (NIST), the Federal Emergency Management Agency, and the Department of Homeland Security; and by the private sector such as Kaiser Permanente, IBM, and Citi Bank. Significant amounts of money, time, and human resources have been invested in resilience—conceptually, analytically, and in practice.

But despite the growth and investments in resilience efforts, resilience science and measurement still lag behind resilience practice, and key questions remain: What is the current state of the science in community resilience measurement?

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How well do the designs of measurement efforts match the practical needs and demands of end users? How well has resilience measurement been translated into action at local to national scales? Has measuring resilience made a difference? If the concept of community resilience can and should be measured as indicated in the National Research Council's report *Disaster Resilience: A National Imperative* (2012), then there is a need for basic measurement efforts that are useful, usable, and used (Aitsi-Selmi, Blanchard, and Murray, 2016; Wall, McNie, and Garfin, 2017).

Charges 1, 2, and 3 of the Statement of Task (see Box 1-2) call for an examination of resilience measurement scholarship and practice under way and a description of the similarities and differences among these efforts and the methodologies they use for data collection and analysis. This chapter addresses these charges through an assessment of 33 community resilience measurement efforts, policies, and programs designed to capture various aspects of resilience (see Box 2-1 for Chapter 2's findings).

ASSESSMENT OF CURRENT RESILIENCE MEASUREMENT EFFORTS

The committee reviewed dozens of measurement efforts and relied on its expertise—representing diverse academic disciplines (sciences, engineering, human health) and community resilience experience (researchers, funders, practitioners)—and the resilience literature to narrow the list to 33 efforts. These 33 efforts are meant to represent a diverse sample of currently available community resilience tools and frameworks. The committee sought to examine resilience measurement efforts that specifically purport to assess community resilience or provide guidance to resilience assessment. The committee was not charged with finding specific resilience measures, metrics, or indicators, nor was it charged with either identifying the best or most applicable measurement efforts for communities or providing a comprehensive list of resilience measurement tools and frameworks. Rather, the committee was charged with documenting the similarities and differences among these different approaches and describing methodologies used for quantitative and qualitative data collection and analysis.

The committee identified dozens of measurement efforts through literature reviews and committee members' professional knowledge about the current state of practice (e.g., Beccari, 2016; Cutter, 2016b; NRC, 2012; ODI and RMEL CoP, 2016; Ostadtaghizadeh et al., 2015; Sharifi, 2016). There are overviews of many of the current efforts in the literature (e.g., Cutter, 2016b; NIST, 2016; ODI and RMEL CoP, 2016) that describe the basic measurement elements (e.g., purpose, target categories, scale, and/or type of measurement). Because few of these overviews offer detailed comparative analyses, communities are challenged to distinguish among the different measurement efforts or identify which measurement tool might be best for their individual purposes.

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Resilience measurement efforts vary widely and include: (1) defining and explaining (or operationalizing) a specific resilience construct, indicator, or community capital; (2) promotion of checklists or scorecards that centrally assemble indicators or subjects associated with community resilience; (3) processes and guidance to communities on indicators or subjects that could be measured locally; or (4) the encouragement of the use of specific databases, analytical methods, or tools for communities' use in measuring. The intent and design of the measurement effort determines whether it is a holistic accounting of community resilience for any context, a specific instance (past, present, future) or case (place), or an exploration of community conditions. Virtually all resilience measurement efforts that the committee considered attempt to describe the current resilience of a community (often, as an exploratory diagnostic) rather than predict what the future resilience of a community could be if it took certain actions in the present. None of the measurement efforts captures the full variety of operational variables for community resilience.

The committee assessed community resilience measurement efforts to describe the current state of scholarship and practice, explicitly examining published efforts that are intended to serve as measurements of community resilience. Of the dozens of resilience measurement efforts considered, the committee selected 33 whose methodological development and operational definitions of resilience are publicly available (see Table 2-1; Appendix C provides a brief description of each effort). These 33 measurement efforts include those that focus on data collection, analysis, and interpretation, and those that attempt to measure resilience both before and after events. Because these efforts have not undergone validity testing (see "Construct Operationalization, Reliability, Validity" below), neither scientific rigor of the measurement itself nor its implementation was considered as a selection criterion. Efforts that are intended to measure specific resilience-related concepts—such as social vulnerability or a specific environmental hazard—were excluded since such efforts are not designed to capture the holism of resilience, as encompassed by the six community capitals.

The committee systematically evaluated each of these measurement efforts, paying particular attention to those with a real or potential application in the United States and a focus at the *community* scale, with a noted bias toward geographic communities at a metropolitan or regional scale or smaller. This bias is intentional. As indicated in the National Research Council report *Disaster Resilience: A National Imperative* (NRC, 2012), resilience efforts should provide actionable evidence for policies, programs, and funding allocations for communities (where regional, county, and city or township governments are the primary unit of policy) and serve as vehicles for community engagement and awareness. Therefore, the committee focused its review on measurement efforts that could be applied at this level of geography.

Building on previous reviews of peer-reviewed, professional, and "grey" literature, as well as on global and U.S.-based resilience-explicit interventions,

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TABLE 2-1 The Resilience Measurement Efforts Reviewed by the Committee (listed alphabetically)

Resilience Measurement Effort	Source
Alliance for National and Community Resilience Benchmarking System	The International Code Council
Baseline Resilience Indicators for Communities (BRIC)	Cutter, Burton, and Emrich, 2010; Cutter, Ash, and Emrich, 2014; Cutter and Derakhshan, 2018
Characteristics of a Disaster-Resilient Community	Twigg, 2007, 2009
City Resilience Index (CRI, also referred to as the City Resilience Framework or CRF)	Arup
Climate Resilience Screening Index (CRSI)	Environmental Protection Agency
Climate Risk and Adaptation Framework and Taxonomy (CRAFT)	Arup (C40, Bloomberg Philanthropies)
Coastal Resilience Decision Support System	The Nature Conservancy
Coastal Resilience Index	Mississippi-Alabama Sea Grant Consortium and NOAA Coastal Storm Program
Community Assessment of Resilience Tool (CART)	National Consortium for the Study of Terrorism and Responses to Terrorism (START)
Community Disaster Resilience Index (CDRI)	Texas A&M
Community Resilience Indicators and National-Level Measures	Federal Emergency Management Agency
Community Resilience Manual	The Canadian Centre for Community Renewal
Community Resilience Planning Guide	National Institute for Standards and Technology
Community Resilience System (CRS)	The Community and Regional Resilience Institute (CARRI)
Community Resilience: Conceptual Framework and Measurement	U.S. Agency for International Development
Community-Based Resilience Analysis (CoBRA)	United Nations Development Programme Drylands Development Centre
Conjoint Community Resilience Assessment Measure (CCRAM)	Ben-Gurion University of the Negev's Prepared Center for Emergency Response Research and Tel-Hai Academic College

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TABLE 2-1 Continued

Resilience Measurement Effort	Source
Disaster Resilient Scorecard	IBM and AECOM
Disaster Resilient Scorecard for Cities	The United Nations International Strategy for Disaster Risk Reduction, IBM, and AECOM
Earthquake Recovery Model	SPUR (San Francisco Planning + Urban Research Association), 2008
Evaluating Urban Resilience to Climate Change	Environmental Protection Agency
Flood Resilience Measurement Framework	Z Zurich Foundation
Framework for Community Resilience	International Federation of the Red Cross
Indicators of Disaster Risk and Risk Management	Inter-American Development Bank
National Health Security Preparedness Index	Centers for Disease Control and Prevention and the Robert Wood Johnson Foundation
PEOPLES Framework	National Institute for Standards and Technology
Resilience Capacity Index (RCI)	Foster, 2011; OPDR, 2012
Resilience Index Measurement and Analysis (RIMA)	United Nations Food and Agriculture Organization
Resilience Inference Measurement (RIM)	Lam et al., 2016
Resilience Measurement Index (RMI)	The Infrastructure Assurance Center at Argonne National Laboratory
Resilience Scorecard	Berke et al., 2015
Resilience United States (ResilUS)	Miles and Chang, 2011
Rural Resilience Index (RRI)	Cox and Hamlen, 2014

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the committee assessed the 33 resilience measurement efforts according to three categories: content (what is being measured), use (the intended or actual use of the tool or framework), and status (the current state of its development or implementation). In addition, the committee noted thematic, aspirational aspects of the efforts including their being adaptable to the unique characteristics of communities and across multiple capitals; scalable for community size and needs; quantifiable; easy to use; and/or integrated across diverse stakeholders and decision makers. The degree to which the various measurement efforts embody these characteristics is discussed below within the context of each measurement's content, use, and status.

Content: What the Measurement Effort Is Measuring

The committee analyzed what each of the measurement efforts attempted to define by looking at what the measurement effort does across eight subject areas (see Table 2-2). These areas ranged from the focus of the measurement effort (e.g., event types, geographic context, disaster stage) to attributes of the effort itself (e.g., unit of analysis, type, approach, capitals, structure).

Each of the Content Subjects highlighted in Table 2-2 that are used to assess resilience measurement efforts is described below.

Capitals: Does the measurement effort capture the multiple dimensions or capitals of resilience?

The types of shocks and stressors and the purpose of the measurement influence which of the community capitals are incorporated into the measurement effort. A resilience measurement effort may capture one, several, or all of the six capitals. In the early phase of resilience measurement development, there was a focus on natural hazards, and consequently, the physical aspects of resilience were often prioritized (Aldrich, 2012; Aldrich and Meyer, 2015). However, the committee's review of the resilience literature highlighted the importance of the role of social capital and cohesion in response to adverse events, economic and financial preparations to and impacts from these events, and the political will to invest in both mitigation and recovery. In general, resilience measurement efforts are increasingly integrating the multiple dimensions of resilience. And, recently developed efforts that do not consider all of the community capitals—for example, Argonne National Laboratory's Resilience Measurement Index and NIST's Community Resilience Planning Guide, which focus on the built environment—acknowledge that there are other components of resilience phenomena and activities that their efforts do not address.

Despite this increased awareness of the multidimensional nature of resilience, many efforts still do not integrate the various dimensions. Typically, this exclusion does not exist as a rejection of the broader multidimensional definition

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TABLE 2-2 Characteristics Used to Assess the Content of Current Resilience Measurement Efforts

Content Subject	Relevant Characteristics
Capitals (Tierney, 2006)	Natural Built Financial/economic Human/cultural Social Political/institutional
Adverse event (Choularton et al., 2015)	Acute or chronic shocks or stressors Natural shocks or technological shocks Universality/shock neutrality or singular shocks
Context (Moench, 2014)	Urban Rural Coastal Inland Universal Site-specific
Disaster event stage (MacAskill and Guthrie, 2014)	Mitigation and preparedness Relief and response Recovery Long-term community planning or nontemporal
Object of analysis (Cutter, 2016b; Sherrieb, Norris, and Galea, 2010)	Asset-based Capacity-based Combination of assets and capacities
Community unit of analysis (Sirotnik, 1980)	Administrative boundaries below municipal borders (neighborhood) Municipal boundaries (city-wide) Administrative boundaries above municipal borders (regional) Nonadministrative or user-defined community Sum or average of smaller unit in community (households, buildings, etc.) Administrative or environmental unit equal to the community (city government, watershed, etc.)

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TABLE 2-2 Continued

Content Subject	Relevant Characteristics
Data type, source, quality (Olsen, 2011)	Qualitative Quantitative Mixed-methods Primary data Secondary data Community data collection Self-reported Independently assessed and reliable Representative Anecdotal Frequent data collection Single data collection (to date)
Construct operationalization, reliability, validity (Shadish, Cook, and Campbell, 2002)	Aggregation Un-aggregated Single metric output Reliability testing of individual variables Validity testing with comparable measures

of resilience, but is due to the need to operationalize resilience for a specific purpose, such as a building department looking at measures of resilience for the built environment only. A few efforts focus on one capital but also reflect on its relationship to others (e.g., the NIST Community Resilience Planning Guide and the National Health Security Preparedness Index). Collectively, the measurement efforts assessed by the committee have produced a rich set of variables and data collection opportunities that could inform new integrative approaches to measure across resilience dimensions. For example, in the Environmental Protection Agency's Climate Resilience Screening Index, The Nature Conservancy's Coastal Resilience Decision Support System, and Argonne National Laboratory's Resilience Measurement Index, the environmental conditions and projections of critical infrastructure indicators are directly connected to relevant literature in those fields while simultaneously relevant to community resilience.

In general, resilience measurement efforts provide an incomplete view of community resilience by assuming that measurement of only one or two of the capitals is the equivalent of measuring overall community resilience—in other words, they ignore the foundational premise that community resilience is multidimensional (see Figure 2-1).

***Finding 2.1*. Few of the measurement efforts consider all of the six commonly used community dimensions or capitals.** Gaps in coverage of all six community capitals limit a resilience measurement effort's robustness in measuring the holistic nature of community resilience.

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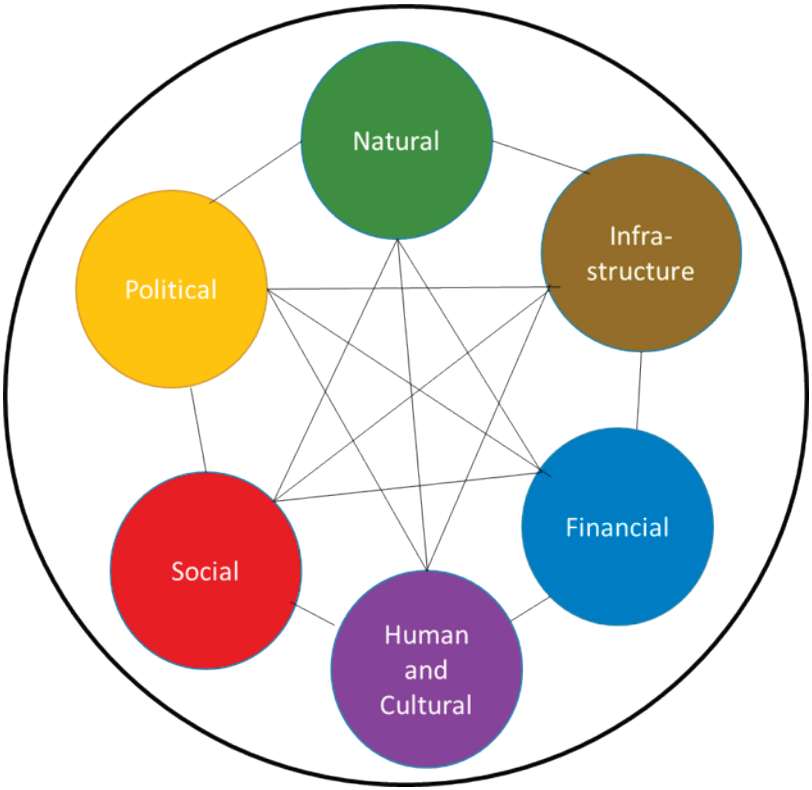

Figure 2-1 The multidimensional nature and interconnectedness of community resilience capitals are the foundation for measurement efforts from local to global scales.
SOURCE: Measuring Community Resilience Committee.

Adverse Event: Does the measurement effort focus on one kind or a variety of adverse events?

Disaster Resilience: A National Imperative (NRC, 2012) defines resilience in relation to "adverse events." A resilience measurement effort may be agnostic to the shocks and stressors to which a community is exposed (universal) or it may explicitly focus on a singular shock or stressor or a select combination (singular). For example, a resilience measurement effort may be designed to capture a system's ability to bounce back from flooding (a natural, acute adverse event), homelessness (a nonnatural, chronic adverse event), the effects of climate change (multiple natural, chronic, and acute adverse events), or dam failure (a nonnatural, acute adverse event).

The concept of an adverse event is implicit in all resilience measurement efforts but not necessarily represented explicitly by specific variables or indicators.

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For example, some nonspecific hazard-related efforts as well as pre-hazard-preparedness measurement efforts include general public emergency management capacity indicators. These tend to measure only the *existence* of such a function in a local government, such as the presence or absence of an approved disaster recovery plan, rather than the *quality* of the plan or the capacity to implement it.

Approximately half of the community resilience measurement efforts reviewed do not specify a specific adverse event type. Of those that do, the largest subset is focused broadly on natural hazards, often related to climate change. For example, a measurement effort assesses specific contributors to resilience against numerous effects of climate change (e.g., increased severe weather events, sea level rise) or focuses on a single effect (e.g., sea level rise). A handful of the efforts reviewed address only a specific hazard type (e.g., San Francisco Bay Area Planning and Urban Research Association's (SPUR's) Earthquake Recovery Model and Zurich Flood Resilience Measurement Framework). Many, such as the City Resilience Index and the Resilience Capacity Index, propose an even broader definition of shock to include social and economic adversity.

Context: Does the measurement effort apply to an entire subset of geographic conditions or to site-specific exposure profiles?

Every community is characterized by a unique set of social, environmental, cultural, economic, and institutional conditions. A resilience measurement effort may select a universally defining set of measurements, which are then applied to all communities within a region, country, etc.; may be tailored to a specific sample of communities (urban, rural, coastal, etc.); and/or may utilize a unique set of characteristics applicable only to select communities. While most efforts do not specify the geographic locations or contextual categories to which they should be applied, several are explicitly intended for a specific geographic area or community size. For example, the Rural Resilience Index is exclusively focused on rural communities, the City Resilience Index is most relevant to urban areas, and the Earthquake Recovery Model is (not surprisingly) relevant to earthquake-prone areas. Many of these place-specific efforts use similar dimensions as non-contextual ones and vary only in the operationalization of indicators and the types of data used or proposed for use.

Disaster Event Stage: Does the measurement effort apply to one stage of a disaster cycle or to an ongoing condition or capacity?

The definition of resilience from *Disaster Resilience: A National Imperative* (NRC, 2012) includes all periods before, during, and after an adverse event. Using a resilience measurement effort to identify which areas in a community are performing well or poorly is useful for general community planning purposes. Alternatively, the use of a measurement effort may be more nuanced, such as tracking and capturing changes over space and time with regard to post-disaster

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recovery, assessing progress in mitigating adverse outcomes, or examining the effectiveness of resilience project investments.

An ongoing debate in the resilience literature and practice around the definition of resilience is whether resilience should be operationalized as (1) the ongoing condition that precedes an adverse event that enables a community to bounce back, or (2) by the bouncing back itself (Cutter, 2016b; Patel et al., 2017). Most of the resilience literature argues for the former but does not necessarily dismiss the latter as an outcome of interest.

Most community resilience measurement efforts approach resilience as a general condition that fluctuates with time and in relation to an adverse event. A handful of the efforts considered in this report focus solely on post-disaster recovery measures (e.g., the Conjoint Community Resilience Assessment Measure, the Earthquake Recovery Model, and Resilience United States). The differences in approach are helpful for advancing the field in the long term, since change in a pre-disaster capacity measurement should correlate with expected disaster losses and post-disaster recovery times and qualities.

Object of Analysis: Does the measurement effort focus on a community's assets or its capacities?

The purpose and utility of a resilience measurement effort have an influence on the number and choice of variables or indicators and the information these convey. Some efforts rely on variables and indicators that count what *is* currently within a community, as opposed to what *can be*. Asset-based indicators capture information on what assets or resources exist within a community. Capability or capacity-focused indicators communicate a community's ability to be resilient in the face of a shock independent of the absolute number of assets.

Variations in asset-based versus capability-focused indicators were noted by the committee as potentially being a useful source of distinction in measurement efforts. The community resilience measurement efforts reviewed for this report typically combined both in some fashion, but tended to rely more on asset-based indicators (e.g., Baseline Resilience Indicators for Communities and the Zurich Flood Resilience Measurement Framework) because data are more readily available and because the literature on capacity measurement is more nascent. A few of these measurement efforts are capacity-based such as Community Assessment of Resilience Tool, Community Resilience Indicators and National Level Measures, and the Resilience Capacity Index.

Community Unit of Analysis: Does the scale of the measurement effort correspond to the definition of the unit of analysis—"community"—that is being measured?

A "community," defined as a subnational and substate geography (see Chapter 1), was the unit of analysis for all the resilience measurement efforts the committee reviewed. The unit of analysis used to define a community is generally

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an administrative boundary (e.g., zip codes, census tracts/block, cities, counties, metropolitan statistical areas), and the measurement efforts reviewed by the committee vary somewhat on the specific geographic boundary in question. For example, Baseline Resilience Indicators for Communities measures resilience at the county level whereas the City Resilience Index does so at the city level (but with significant slippage into the use of regional, state, and national level data sources in cases where the indicator does not apply to a city scale or in which city-scale data are not available). In theory, however, these measurement efforts could be used for other units of analysis used to define a community.

The measurement efforts reviewed use a variety of community-level data sources that come from different units of analysis within a community such as parcel boundaries, topographic groups, households, or political districts. Many resilience measurement efforts that have been operationalized define communities using a combination of institutional capacities (e.g., government functions) measured at a single community unit and smaller units (e.g., household counts) within a community.[1] More holistic measurement efforts typically use many kinds of data sources. But the more data sources that are used (e.g., environmental data, health data, and demographic), the greater the chance that they are measured on different spatial and temporal scales, which could create challenges in combining them to effectively measure the unit of analysis being used to define the community.

Data Type, Source, and Quality: What types of data are collected to conduct the measurement?

Are the variables and indicators quantitatively or qualitatively measured? What are the data sources for the measurement effort's variables? What is the quality of those data? How often are the data collected? The analytical nature of the data within a community resilience measurement effort often dictates whether any group or composite measure is comparable across communities. As mentioned above, the data format used in a resilience measurement may be qualitative (e.g., present/absent, complete/incomplete, high/low) or quantitative. Quantitative data range from absolute values (e.g., number of doctors) to standardized (e.g., percentages) or normalized values. Occasionally, a mixed-methods approach is used in which both qualitative and quantitative data are employed. Depending on the measurement effort's purpose, both types of data and resultant indicators are

[1] There are instances in which operationalizing various units becomes problematic. For example, nonwhite households generally have less access to resilience-supporting services and resources; this is typically operationalized with a count of the number or proportion of nonwhite households in a community. However, having nonwhite households that have less access to resilience-supporting services and resources may represent a potential proxy variable of structural racism or white privilege—an underlying process that is more difficult to adequately measure but nonetheless influences the unequal access to resilience services and resources (Gee and Ford, 2011; Pulido, 2000).

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useful and provide a richness of information along with the potential for community comparisons over time.

Establishing the quality of data used in resilience measurement is important because there may be variations in how data are collected that may not allow for comparison and contrast across difference processes, capabilities, organizations, sectors, etc. within the same community over a long period of time (Carmines and Zeller, 1979). For example, some data may be collected in regular intervals (e.g., quarterly, annually, biannually) while other data may be collected as part of a one-time effort (e.g., to define resilience goals or priorities, or to provide a proof of concept).

The measurement efforts reviewed by the committee employed quantitative data, qualitative data, and/or a combination of both. Approximately half of the efforts rely solely on quantitative data, which requires availability of and access to large quantitative data sets. For example, Baseline Resilience Indicators for Communities and the Community Disaster Resilience Index focus on quantification to produce a comparable set of dimensional measures. The Coastal Resilience Index, on the other hand, relies on expert judgments based on qualitative data. The City Resilience Index combines both quantitative and qualitative indicators. Test-retest activities for hybrid composite measures must be conducted to ensure that the data, proposed quantification scales, and indicators are reliable. The National Health Security Preparedness Index is a good example of the test-retest activities and subsequent adjustments in their measurement effort.

Among the measurement efforts, there are generally two approaches to sources of data. The most common approach is a reliance solely on national data sources such as the U.S. Census Bureau's American Community Survey or Federal Emergency Management Agency flood maps, despite their known limitations. This is the case with Baseline Resilience Indicators for Communities, Community-Based Resilience Analysis, Resilience Capacity Index, Resilience United States, and the Resilience Measurement Index, reflecting their quantitative and comparative approaches to measuring communities' resilience, and to some extent The Nature Conservancy's effort, which also overlays environmental data from a variety of nationally credible sources. National data are limited by the low frequency of national collection and by geography—that is, desired data often do not exist at the most appropriate level of granularity such as a case where the available data are at the county level but neighborhood-level data would be more reflective of the underlying resilience indicators. The second approach is a combination of national and local data sources, often with qualitatively derived local data from focus groups, interviews, and expert review, an approach favored by the City Resilience Index and the Zurich Flood Resilience Measurement Framework. For qualitatively derived primary data, there is no clear test-retest protocol, triangulation, or other analytics used to ensure the quality of the data. These methodological techniques are needed to construct validity of qualitative data.

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Construct Operationalization, Reliability, Validity: How does the measurement effort place individual variables and their indicators into a holistic or aggregate structure?

The configuration of a resilience measurement effort is closely tied to its purpose and utility. For example, a resilience measurement effort may be a simple list of characteristics with little or no post-processing of the collected data (quantitative or qualitative). Certain components or data inputs may be combined and aggregated to synthesize information at different levels (e.g., capitals or objects of analysis). Or, all input data sets and measurement levels may be aggregated to produce a single, numeric output, referred to as an index.

Box 2-2 illustrates known procedures and steps for constructing indexes of various types to help researchers understand the inherent limitations and/or biases in their tools. As Box 2-2 indicates, an important methodological step to ensure a robust measurement effort is validity testing, in other words, testing to confirm that the resilience measurement is gauging resilience and not some other characteristic such as sustainability, economic productivity, inclusivity, equity, or vulnerability. There are two ways to assess validity. Convergent validity looks at whether individual variables correlate with other constructs that measure similar

BOX 2-2
Steps in Composite Index Construction

- Identification of conceptual framework: theoretical or conceptual basis for index
- Structural design: organization of variables within index (deductive, inductive, hierarchical)
- Determination of analysis scale: geographic aggregation level
- Indicator selection: proxy variable used to represent various dimensions
- Assessment of measurement error: accuracy and precision of the input data
- Data transformation: how each variable is represented (raw counts, density, percentages)
- Normalization: standardization of variables to a common unit (linear scaling, z-scores)
- Weighting: relative importance of each indicator (equal, expert-judgment)
- Aggregation: combination of normalized indicators into final index (additive, geometric, etc.)
- Validity testing: tests of internal consistency; comparison of output to known correlates
- Uncertainty and sensitivity analysis: inherent randomness, imprecise knowledge or data

SOURCES: Becker et al., 2017; Joint Research Centre, 2008; Paruolo, Saisana, and Saltelli, 2013; Tate, 2012, 2013.

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phenomena; predictive validity looks at whether individual variables can predict those other constructs. The measure should highly correlate with other measures typically associated with community-scale resilience, such as recovery times and costs, and predict outcomes affected by resilience such as hazard losses.

Another key step for building a robust measurement effort is reliability. A fundamental point of measurement is to ensure that identical units score in identical ways across different time points and survey modalities (Carmines and Zeller, 1979). In other words, the reliability of a resilience measurement effort depends on the ability of users to reproduce the same results for the same community. Thus, an important step in the structure of a measurement effort is the testing and re-testing of reliability activities needed for each indicator's data. The reliability of a measurement effort's output has to do with its internal consistency—that is, how each contributing variable "hangs" with the others, and whether and how it ultimately contributes to the overarching construct of community resilience. It is important that the various indicators are coherent and individually contribute to the intended measurement, irrespective of whether a single resilience dimension (e.g., economic) is being measured or a resilience composite measure is being generated. The degree to which inferences can be made from measured observations (also known as construct validity) is especially challenging when measuring things that do not have natural units of measurement. Even in those cases, a range of uncertainty is possible either because the measurement is predictive rather than actual (such as ranges of climate change effects) or because the tests from which measurements are drawn are not reliable (from inadequate survey instruments, for example). Generally, most resilience measurement efforts do not adequately consider test-retest reliability assessment in data collection or fully disclose confidence intervals in observations.

Almost all the efforts the committee assessed relied on an inductive selection of indicators to start their exploration; however, only a handful of these have revisited and revised their selection of indicators. Of the ones that have done so, only four have performed any internal consistency analysis that is available publicly: Baseline Resilience Indicators for Communities, the Community Disaster Resilience Index, Conjoint Community Resilience Assessment Measure, and the Resilience Inference Measurement. The committee found few community resilience measurement efforts with documented reliability and validity analyses (though, admittedly, methodological rigor is not always a purposeful intention of their development).

None of the operationalized measurement efforts has undergone the complete methodological testing for composite statistics, as is typical in other fields of measurement such as psychometrics or medical prognostic indicators. One effort, Resilience United States, was tested against a single actual hazard event for its predictive value, but this was more of a reliability test than a validity one because of the post-disaster recovery nature of this effort. The lack of validity testing is likely more reflective of the nascent stage of operationalized efforts than of their developers' attempts at measurement rigor.

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Use: The Intended or Actual Use of the Measurement Effort

Because of the individualized application of many of the resilience measurement efforts examined for this report, the committee analyzed the underlying purpose of each and assessed whether the intended purpose directly shaped the usefulness, transferability, and applicability of the measurement effort itself. The use subject areas include the intended purpose of the effort, the process employed, and the ease of use (see Table 2-3).

Purpose of the Measurement Product: What is the intent of the measurement effort and how does that influence the quality, reliability, and complexity of its use?

Understanding why any of the reviewed measurement efforts were created and their intended and actual applications provides critical insight into how the measurement effort was operationalized. In a few cases, the output of these efforts is a single number or qualitative value for a community that is meant to describe a current state or prescribe a desired one. This is especially true of efforts produced within scholarly circles without actual application, and among those designed for reflection and engagement within a community. For other measurement efforts that have been operationalized, such as the Baseline Resilience Indicators for Communities and The Nature Conservancy's effort, the output is a comparison of these values between communities for the purposes of self-assessment and local action.

Many diagnostic measurement efforts are intended to be used for national or state decision making or investment prioritization. While there has been movement toward this purpose—such as the Federal Emergency Management

TABLE 2-3 Characteristics Used to Assess the Use of Current Resilience Measurement Efforts

Use Subject	Relevant Characteristics
Purpose of measurement: Effort's product	Prescriptive Descriptive Diagnostic Evaluative
Purpose of measurement: Effort's process	Community engagement Scholarly inquiry Investment decisions or prioritization Mandate as part of a program or initiative
Effort's complexity	Resources needed (e.g., knowledge, software, staff) Ease of use, accessibility of product Practicality of implementation

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Agency's 2017 push toward a National Risk Index[2] that relies on some of the underlying measurement efforts that evolved into those reviewed here as well as on the varied efforts by the Environmental Protection Agency and U.S. Agency for International Development—the committee found only a few examples of the direct application of resilience measurement efforts for decision making. In at least one case (The Nature Conservancy), the measurement effort had been employed because the decision to invest resources or activities in a specific community had already been made. Some of the measurement efforts used for community visioning exercises (e.g., the City Resilience Index) have led to local policy and program changes, or at least offering activities to address some of the challenges in the visioning process (e.g., Zurich Flood Resilience Measurement Framework; also see Box 2-3). The committee, therefore, could not assess the effectiveness or impact of the resilience measurement efforts on those resilience interventions or on variations of investments (such as efficacy, efficiency, and equity) at this point in time.

Purpose of the Measurement Process: What is the intention of the process in which the measurement is created and applied, if any?

In several instances, the exercise of producing or applying a measurement effort has an implicit purpose that is just as significant as the end product. For example, a measurement effort that seeks to gather input from community residents (bottom-up measurement efforts, discussed below) could satisfy the need for engagement as well as integrate that input into top-down efforts by private investors or higher-governance entities such as states or nations that may need the resulting measurement for prioritization or decision making. Sometimes, the *process* of measuring is more important than the outcome—particularly if it is designed to elicit some sort of action, policy, or program in support of community resilience.

Many of the resilience measurement efforts the committee examined have been used in community engagement activities by local governments or civil sector entities. In some cases, such as the National Oceanic and Atmospheric Administration's Coastal Resilience Index and the NIST Community Resilience Planning Guide, the efforts are intended as community engagement efforts with resilience ostensibly to raise awareness and provide guidance for decision making. In others, the efforts engage citizens in selecting and measuring predetermined indicators (e.g., Zurich Flood Resilience Measurement Framework and the City Resilience Index). However, for a handful of measurement efforts (e.g., Baseline Resilience Indicators for Communities and the Resilience Inference Measurement) that fall under the top-down development process, the purpose of the measurement effort's output is to inform local actors and other stakeholders about resilience conditions and suggest opportunities for change. There are a handful of

[2] For information about the National Risk Index: http://riskindex.atkinsatg.com.

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top-down efforts (e.g., the United Nations Office for Disaster Risk Reduction's Disaster Resilient Scorecard for Cities) that are mainly procedural checklists for conducting resilience-related activities or embarking on resilience conversations that ultimately translate into the beginning of the process of measurement.

In addition to measuring resilience, one goal of a resilience measurement process may be one of scholarly inquiry; for example, the Zurich Flood Resilience Measurement Framework was beta tested in several countries to help the developers identify the best indicators of flood resilience and improve the framework. A resilience measurement may also be mandated as part of a program or initiative.

Complexity: Is the measurement effort feasible and does it result in actionable information?

The entire process of collecting and analyzing data and synthesizing the information to generate an assessment of resilience in or across communities can be resource-intensive, inaccessible to the citizens or policy makers within the communities, and/or impractical, thereby limiting its usefulness.

The level of complexity in the number and quality of indicators and resulting tabulations in a resilience measurement effort can be challenging to communicate and undertake, and make it difficult to implement. This challenge presents a measurement conundrum where user-friendly efforts are wanted but simplistic methodologies do not (yet) exist to produce such efforts unless dimensions of resilience are foregone or the applicability is very narrow. Most of the measurement efforts the committee examined have retained their level of complexity in order to be true to the goal of measuring resilience by employing data transformation techniques that are incomprehensible to the end user. Other measurement efforts (e.g., the Resilience Capacity Index) that have traded complexity for fewer and more accessible explications of indicators have, in contrast, lost a significant amount of empirically defined reliability and validity.

Status: Current State of Development or Implementation of the Measurement Effort

Because resilience measurement is still in its infancy, most of the efforts that have been developed and implemented to date have had limited application and impact. To document the status of various efforts, the committee relied on current documentation and professional knowledge of each effort's theoretical and practical evolution. The committee also evaluated the level of community engagement both in the effort's development and with regard to its communication at a community level, since this has been an underlying motivator for many measurement efforts. Table 2-4 lists the three subject areas that were explored.

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TABLE 2-4 Characteristics Used to Compare the Status of Current Resilience Measurement Efforts

Status Subject	Relevant Characteristics
Development stage of the effort	Inception Peer-reviewed Implementation case studies (similar context) Implementation case studies (different context) Informational stage only Action or policy stage
Frequency of effort's application (to date)	One-time Intervals
Creation and use process	Co-development Top-down (government, scholar, or organizationally led) Bottom-up (community level)

Development Stage: Where is the measurement effort along the development and use life cycle?

Developing a theoretical construct of measuring resilience overall or a singular application is a process that includes the initial design phase (inception), scientific review and testing (peer-review), and implementation in similar (e.g., developing countries, cities, coastal areas) or different contexts, with respect to the context for which a resilience measurement was originally designed. The committee considered the overall rate of production of new resilience measurement efforts and the status of existing ones.

The number of resilience measurement efforts continues to grow, but the rate of growth appears to have tapered in recent years, and there have been surprisingly few applied efforts to measure community resilience. Most efforts continue to focus on varying definitions of resilience, schematic frameworks, and potential indicators, but not on operationalizing definitions, conducting exploratory testing of the reliability and validity (internal and external) of the effort's output, or collecting and testing data. These efforts are not without their merit and, in some cases, the developers had no intention of moving beyond exploration or focusing on a specific dimension of resilience. Notable efforts in this subset of early efforts are the NIST Community Resilience Planning Guide, the Resilience Scorecard, and the Resilience Inference Measurement. Efforts that have advanced the field into implementation include Baseline Resilience Indicators for Communities, the City Resilience Index, Community-Based Resilience Analysis, the Community-Based Resilience Analysis, the Community Disaster Resilience Index, Climate Resilience Screening Index, the Disaster Resilience Scorecard for Cities, and the Zurich Flood Resilience Measurement Framework.

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Replication and Frequency: Has the effort been applied more than once?

Among the resilience measurement efforts that have been piloted in communities, only a few have been applied more than once in the same community or in more than one community. As of early 2019, the City Resilience Index, the Disaster Resilience Scorecard, and the Zurich Flood Resilience Measurement Framework have undergone or are currently piloting in more than one community, in a wide range of a few to over 100 communities, although the results of these pilots have not been widely publicized. Part of the reason for the low frequency of application is that underlying data for many efforts (like the Baseline Resilience Indicators for Communities) are themselves not updated frequently. More comparative efforts like Baseline Resilience Indicators for Communities, Conjoint Community Resilience Assessment Measure, and Resilience Inference Measurement have been updated two to four times with newer data. Another common reason for the lack of frequent and repeated measurement attempts is the lack of resources for conducting a measurement effort beyond a preliminary assessment or diagnostic, especially for those efforts reliant on qualitative data.

Creation and Use Process: Has the effort relied on a top-down or a bottom-up process in its development and/or dissemination?

The design of a resilience measurement effort may be the result of a co-creation process between a community or communities and resilience experts in the consulting, government, and/or academic sectors, or may be developed by just one side—either from the bottom-up (the design principles emerge from the community) or from the top-down (experts act in isolation).

Among the resilience measurement efforts that have been used more than once—either in the same communities or in multiple communities—only a few have been updated or refined to improve their usability and/or usefulness. Some efforts initially designed to be community engagement tools have not been implemented as operationalized measurement efforts. But a few of these have moved to the implementation phase, especially those that rely on qualitative data. For example, the City Resilience Index and the Zurich Flood Resilience Measurement Framework have engaged in a hybrid of bottom-up, top-down strategy using predetermined indicators to elicit responses from citizenry and/or leadership. The Zurich Flood Resilience Measurement Framework, for example, has been implemented in dozens of communities (twice in each community) across the world as of early 2018, and its developers have used the data and results from these implementation efforts to validate and update the framework. Most measurement efforts that were developed in more formal top-down approaches have been replicated in the same communities or updated, but without any significant community-level input.

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EXAMPLES OF COMMUNITY RESILIENCE MEASUREMENT

Two examples of communities measuring resilience are highlighted in Boxes 2-3 and 2-4. It is worth noting that both of these measurement efforts were underwritten or undertaken with an influx of intellectual support or financial resources (e.g., from NIST, Z Zurich Foundation, Resilient America Program). Box 2-3 highlights the implementation of the Zurich Flood Resilience Measurement Framework in Cedar Rapids, Iowa, and Charleston, South Carolina, to assess their flood resilience. The Zurich framework, which has been tested in more than 100 communities around the world, considers resilience across five community capitals and considers multiple data sources. Box 2-4 highlights the use of the NIST Community Resilience Planning Guide (2016) in Boulder County, Colorado. The NIST guide has been implemented in six communities. Both of these measurement activities included data collection and rubrics for measuring resilience.

REMAINING GAPS, CHALLENGES, AND OPPORTUNITIES TO IMPROVE MEASUREMENT

Based on its review of 33 measurement efforts detailed in Table 2-1 (and Appendix C), the committee identified a number of limitations and challenges in current resilience measurement science and practice. These challenges can be grouped into three areas: measurement intent, methodological rigor, and application and practicality.

Intent of the Measurement Activity

- In many cases, the resilience measurement effort is a scholarly pursuit meant to contribute to the literature on drivers rather than providing practical guidance for communities.
- Some efforts are techniques that facilitate community engagement and visioning exercises that are undertaken after disaster has struck. The process of trying to define resilience may be more important than the accuracy of the measurement effort's outcome itself.
- The drive to measure is often dictated by policy makers who are motivated to direct governmental funds to specific geographic areas, populations, or activities rather than provide consistent and frequent assessments of all potential factors that could contribute to resilience.

Methodological Rigor

- Comparative studies that evaluate the methodological approaches, intent, and audience of resilience measurement efforts are lacking. In the absence of actual use cases and an assessment of the applicability and reliability of measurement efforts, the tradeoff between more holistic measurement

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BOX 2-3
Implementing the Zurich Flood Resilience Measurement Framework in Cedar Rapids and Charleston

The Zurich Flood Resilience Measurement Framework has been implemented in over 100 communities in nine countries. One goal is to empirically validate the framework and identify which of the 88 sources of resilience are the best indicators of flood resilience. The framework measures flood resilience through the lens of five community capitals (human, social, physical, natural, and financial)[1] and four properties of a resilient system (robustness, redundancy, resourcefulness, rapidity). The framework includes 88 sources (i.e., indicators) of resilience across the five capitals.

The National Academy of Sciences' Resilient Roundtable worked with local partners in Charleston, South Carolina, and Cedar Rapids, Iowa, to better understand their resilience to flooding. Through a partnership with the Zurich Alliance, the Roundtable implemented and tested the Zurich framework in these cities, collecting data across the five community capitals; these capitals represent the community's assets (i.e., its attributes, resources, and capabilities). Those assets that can contribute to a community's resilience to floods represent the sources of resilience. Different kinds of data were collected from and about the community for each resilience source in order to assess the community's level of resilience for that source. Although this project was specifically focused on flooding, the data collected have also been useful in understanding the communities' resilience to a broader set of hazards and disruptions.

The framework is structured around three levels:

1. The five capitals that characterize a community
2. Sources of resilience for each capital
3. Data points for each source of resilience

Data were gathered using one or more of the following data collection methodologies:

- Household surveys
- Community/neighborhood discussions
- Interest group discussions
- Key informant interviews
- Third-party sources

After the data were collected, the Roundtable worked with community representatives to grade each of the 88 sources of resilience based on the data collected about that source and the representatives' knowledge and experience working and living in the community. Each source of resilience was accompanied by a grading rubric. In addition, each source of resilience was tied to a form of community capital, a stage in the disaster risk management cycle, a theme, a resilient property, and a sphere of influence. Therefore, the results can be explored across each of these categories.

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[1] The Zurich Alliance based the five capitals approach on the Department for International Development's Sustainable Livelihoods Framework. See the Sustainable Livelihoods Guidance Sheets at http://www.eldis.org/vfile/upload/1/document/0901/section2.pdf.

SOURCES: Zurich Insurance Group, n.d.

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BOX 2-4
Implementation of the National Institute of Standards and Technology's (NIST's) Community Resilience Planning Guide in Boulder County

The Boulder County Collaborative, a cooperative group consisting of Boulder County and four cities and three towns within it, was formed to direct federal recovery funding from the Department of Housing and Urban Development (HUD) to the most pressing housing and infrastructure needs in the county, regardless of jurisdictional boundary (Boulder County Collaborative, 2016). HUD required that the reconstruction had to adhere to a resilience plan to be eligible for HUD's Community Development Block Grant Disaster Recovery funds. In 2015, the Boulder County Collaborative began using the NIST Community Resilience Planning Guide process as a basis for developing a resilience design performance standard to evaluate reconstruction projects based on established return-to-function goals. The resulting resilience performance standard provides a means to both evaluate and prioritize funding for recovery projects and is also used to serve as a guide for the design of new projects.

The first step in the development of the resilience design performance standard was to apply the guide's process for establishing countywide return-to-function performance goals to all building clusters and infrastructure systems through a series of stakeholder workshops and a separate utility providers' workshop. These were then reviewed and modified based on input from individual focus groups representing the four major cities, three towns, the unincorporated area of the county, and stakeholders that represented cross-jurisdictional interests. Projects under consideration for HUD Community Development Block Grant Disaster Recovery funding that met the established performance goals were then prioritized based on the Colorado resiliency prioritization criteria that uses indicators integrated with sustainability principles. The Wonderland Creek Flood Mitigation Project was one of many HUD funded projects that passed through this process.

efforts and those limited to specific places or capitals that reduce the complexity and make measurement more manageable are currently unknown.

- The connection between input data and measurement design is largely a black box lacking empirical justification for the selection of input data (beyond pointing at existing literature) and design choices for the measurement effort itself. This paucity of evidentiary, objective information makes it extremely difficult for end users to judge the reliability of a measurement effort, identify differences between them, and/or select one that would aid in decision making.
- There is a lack of research identifying the most relevant indicators based on capitals, purpose, context, etc., as well as their measurement and aggregation.
- There is an extensive reliance among the resilience measurement efforts on secondary data, which limits innovation or creativity in terms of more suitable or more accurate data sets.

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Application and Practicality

- Although simplicity should be preferred (as it supports end user interpretation, acceptance, and understanding), it is difficult to achieve due to the multidimensionality of resilience.
- Generally, measurements—especially those relying heavily on aggregating, averaging, or categorizing data—are not designed with repeat assessments in mind that would be capable of capturing changes over time (e.g., semi-annual, annual, bi-annual).
- Local and practical needs (e.g., operational accountability and transparency tools) outpace the existing knowledge base of resilience measurements. The committee's site visits (Chapter 3) revealed a lack of resilience metrics at the very local or project-specific planning level (e.g., for cost-benefit analyses) with dynamic measures able to forecast, or at least estimate, the resilience impact of mitigation projects.

The goals of resilience measurement efforts are sometimes at odds with how they are applied and what they were intended to accomplish. As discussed in later chapters, a few efforts are designed to identify increased investments (such as the NIST Community Resilience Program and Baseline Resilience Indicators for Communities), but do not necessarily make the link from the general resilience conditions they attempt to measure and the specific intervention in which investment might occur. Furthermore, the availability of too many efforts with untested accuracy, reliability, and validity might make the process of measurement seem insurmountable. Resilience practitioners might be confused about which measurement effort is best for them.

Finding 2.2. **Resilience measurement science and practice are not mature enough to clearly articulate which resilience measurement approach is best or works best in practice.**

CONCLUSION

The current state of resilience measurement is not developed enough to reveal a single best measurement approach, scientifically or in practice. They are generally not usable by communities because they are either too difficult, costly, or cumbersome to use or data are not available at the requisite spatial scale. Existing efforts assess capacity, are capital- or sector-specific, and do not address policy or programmatic needs such as targeting for resource allocation, investments, or disaster relief. Many are theoretical or conceptual exercises, and relatively few have been implemented, replicated, or adapted for application. Few resilience measurement efforts are driven by local needs and co-developed with communities, leading to a disconnect between what the effort's developers

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think is relevant and useful knowledge versus what the community desires or can use. In other words, the science of resilience measurement has not been put to the test of practice of implementing strategies to enhance resilience at the community level.

There is a presumption that every resilience measurement effort captures resilience, but this has not been validated. Common methods used in formal resilience measurement include limited quantitative methods to produce an index; qualitative assessments to produce a scorecard or ranking; narratives based on guided qualitative questions to determine capacities and capabilities; and geospatial representations to illustrate intersections of attributes and capacities to compare places. Few efforts follow established indexing guidelines such as testing for sensitivity and internal consistency and data procedures (e.g., weighting, normalization, missing value replacement).

Most community resilience measurement approaches lack temporal sensitivity to monitor change over time. The majority of the existing efforts are single-use applications and have not been applied repeatedly in the same place at different points in time, thus making it difficult to gauge a measurement's ability to track changes over time. Without the ability to capture change over time, measurement efforts lose value as decision-making tools. Furthermore, most of the current efforts are descriptive, not predictive, and do not provide clear guidance about what actions to take to improve resilience. Communities want to design resilience efforts that respond specifically to future predicted challenges. However, a major research challenge persists: how to predict or project a community's future resilience to enable that community to design resilience actions in the present that will address those projected resilience challenges in the future (see Chapter 5).

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3

Ground Truthing How Communities Measure Resilience

BOX 3-1
Chapter 3 Findings

Finding 3.1 Despite the range of available resilience measurement frameworks and tools, many communities are not measuring their resilience.

Finding 3.2 There is not a one-size-fits-all approach to resilience practice and measurement given the diversity of communities.

Finding 3.3 Community organizations often have their own data sources, systems, tools, and platforms that are not compatible with those of other organizations, making it difficult to integrate measurement activities across sectors.

Finding 3.4 Community engagement and buy-in are critical to community resilience.

Finding 3.5 Resilience is multidimensional.

Finding 3.6 Decision makers struggle to determine where resilience investments should be made and what benefits to expect from those investments.

Finding 3.7 Communities are better able to pursue resilience-building efforts when those efforts align with other community initiatives and provide multiple community benefits.

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The term "ground truth" refers to the practice of using direct observation to analyze and verify information (Carp, 2008). The committee "ground truthed" resilience measurement in communities by meeting with local stakeholders.

Charge 4 of the committee's Statement of Task instructed the committee to "confer with community leaders and decision makers . . . about the approaches, challenges, or successes they have encountered in measuring resilience in their respective communities" (see Box 1-2). The committee visited eight communities to learn which measurement frameworks and tools they are using and to understand the successes and challenges they have had in their measurement work. This chapter addresses Charge 4 and presents key findings and observations from these community visits.

The community visits revealed that few communities are actively measuring indicators of resilience or using the resilience measurement tools discussed in Chapter 2. Nonetheless, the community discussions provided useful information about communities' resilience building efforts and the challenges they face in attempting to measure or quantify their resilience successes. This chapter describes the eight places the committee visited, community members' reflections about measuring resilience, and common themes that emerged across this diverse set of communities (see findings in Box 3-1).

COMMUNITIES VISITED

The committee visited seven communities—New Orleans and Baton Rouge, Louisiana; Gulfport and Waveland, Mississippi; New York, New York; and Rapid City and Pine Ridge Reservation, South Dakota—and conducted a videoconference with local government officials in Minot, North Dakota (see Figure 3-1; Appendix D provides a brief description of each community).

The committee sought a diversity of perspectives and selected communities with varied hazards and risk profiles, demographic and socioeconomic profiles, geographic location, and population size. The committee also considered population density, given the differences and variations in the drivers of disaster resilience and capabilities between and within regions (Cutter, Ash, and Emrich, 2016). The committee conferred with leading experts, decision makers, community leaders, and practitioners in local government, the private sector, the nonprofit sector, research centers, and academic institutions. In addition, committee members who worked extensively in communities through the National Institute of Standards and Technology (NIST) Community Resilience Program and the National Academy of Sciences' Resilient America Program briefed the committee about relevant work supporting resilience efforts in Boulder County, Colorado; Cedar Rapids, Iowa; Charleston, South Carolina; Central Puget Sound region, Washington; and Tulsa, Oklahoma. Appendix E provides a brief description of these communities.

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Figure 3-1 Map of the United States marking the location of each community with whom the committee met.

Two of the eight selected communities were large, urban areas and members of the Rockefeller Foundation's 100 Resilient Cities[1] network (New Orleans and New York City), and three were smaller and more rural (Minot, Pine Ridge Reservation, Waveland). Table 3-1 provides a list of recent disasters in the eight communities.

Discussions with local stakeholders provided insights into the challenges of building and measuring community resilience locally, as well as the utility and applicability of resilience metrics and measurement tools such as those discussed in Chapter 2. The committee used these site visits to examine how resilience measurement work is advancing in communities and where knowledge gaps, research directions, and/or opportunities for new approaches exist to realize more healthy and resilient communities within the Gulf region and beyond.

It was especially important that the committee visit communities in the Gulf Coast region since it is a primary focus of the Gulf Research Program (GRP). The first visits were to New Orleans and Baton Rouge, Louisiana, and Waveland and Gulfport, Mississippi, where committee members met with about 90 local stakeholders. These meetings provided perspectives from local government, the state (Louisiana), nongovernmental organizations (New Orleans, Baton Rouge, Gulfport), and academia (Dillard University, Louisiana State University, Loyola

[1] "The 100 Resilient Cities initiative works with cities to build resilience to the physical, social, and economic challenges of the 21st century." For more information: https://www.100resilientcities.org.

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TABLE 3-1 Recent Disasters in the Communities with Whom the Committee Met

Community	Recent Disasters
Baton Rouge, LA	Hurricane Katrina (2005); Hurricane Gustav (2008); Louisiana flood (2016)
Gulfport, MS	Hurricane Katrina (2005); Deepwater Horizon oil spill (2010)
Minot, ND	Train derailment (2002), flood (2011)
New Orleans, LA	Hurricane Katrina (2005); Hurricane Gustav (2008); Deepwater Horizon oil spill (2010); tornado (2017)
New York, NY	September 11 World Trade Center attacks (2001); Hurricane Sandy (2012)
Pine Ridge Reservation, SD	High winds (2015); tornado (2016); tornado and hail (2017)
Rapid City, SD	Black Hills flood (1972); Winter Storm Atlas (2013); ice storm (2014)
Waveland, MS	Hurricane Katrina (2005); Deepwater Horizon oil spill (2010)

University, Tulane University, Xavier University). The committee also met with local government staff involved in the Rockefeller Foundation's 100 Resilient Cities initiative in New Orleans. Site visits to the Gulf Coast region highlighted experiences with large-scale loss of life and property (New Orleans, Waveland) and the implications for port operations and major infrastructure (New Orleans). Furthermore, these visits showed contrasts between smaller towns and cities in Mississippi and large urban areas in Louisiana.

The committee also visited New York City, a city with a high concentration of resilience funders and academic leaders, and met with about 40 local stakeholders, including organizations that fund and lead large-scale resilience programs (e.g., the Rockefeller Foundation's 100 Resilient Cities initiative, Rebuild by Design); staff from seven city agencies; senior leadership from the Port Authority of New York/New Jersey; and representatives from the financial and insurance industries. The committee also met with academic leaders with innovative approaches for measuring resilience.

Finally, the committee chose to investigate smaller and more rural communities to gauge the effect of size on resilience measurement, meeting with stakeholders in Minot, North Dakota, and Rapid City and Pine Ridge Reservation, South Dakota.

In each community, the committee held multiple meetings to converse with specific groups of stakeholders (e.g., from local government, the private sector, nonprofit organizations, research community, public health). Because of the diversity among the communities and stakeholders, the committee developed a set of broad, open-ended questions. The community meetings were designed to elicit responses from stakeholders about resilience measurement and allow the committee to adjust the questions asked and topics explored depending on the

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experiences of people in a given place. The committee took extensive notes during each meeting and discussed commonalities among the sets of notes in closed sessions. Ultimately, those discussions yielded four overarching themes about community resilience and measurement.

The stakeholder meetings in each town or city were open to the public (see Appendix B for the agendas of each community visit). The committee employed a common interview protocol and discussed several broad topics with community stakeholders focused around community goals and priorities, measuring resilience, and resilience challenges. Generally, each meeting began with a discussion about the community's main risks, what it was doing to address those risks, and its goals and priorities. The committee specifically sought to elicit discussion about measuring resilience and as such introduced three broad sets of questions:

1. What initiatives are you undertaking to measure your community's resilience?
2. How are you measuring your community's resilience? What tools are you using?
3. What aspects of community resilience are critical to measure, and what are the challenges associated with measuring resilience?

All of the communities the committee met with had experienced a disaster within the lifetime of the meeting participants. These stakeholders therefore understood the importance of preparing for future events and discussed mitigation efforts against future disasters. Some did not use the term "resilience" in reference to their preparation and mitigation activities, but resilience thinking and approaches were evident in their efforts to reduce or adapt to known hazards and risks; recognize and address acute and chronic shocks and stressors; increase individual preparedness; and/or strengthen their community through community engagement and partnerships.

COMMUNITY DISCUSSIONS ABOUT MEASURING RESILIENCE: FINDINGS AND OBSERVATIONS

During the site visits, the communities discussed their resilience goals, challenges, and needs. Several communities had initiated formal resilience programs and projects; however, they were not measuring the progress of those efforts. None had formal resilience measurement programs in place, and most had not used any of the resilience measurement frameworks or tools discussed in Chapter 2 because they did not know about these tools, how to start the process, or which measurement tools to use. ***Finding 3.1.*** **Despite the range of available resilience measurement frameworks and tools, many communities are not measuring their resilience.**

The communities differed with respect to their challenges, goals and priorities, risk profiles and hazards, where they focus their resilience-building efforts, and how they implement resilience activities. The range of needs, priorities, and

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capacities across these eight communities was broad. ***Finding 3.2*. There is not a one-size-fits-all approach to resilience practice and measurement given the diversity of communities.** Even if these eight communities were actively measuring their resilience, the differences among them were too broad for a single resilience measurement approach to work for all eight.

Though many communities are not formally measuring their resilience, a variety of entities in and operating on behalf of communities track certain aspects of their resilience often related to wellbeing and quality of life. For example, the Data Center, an independent organization that combines multiple sources of data to help decision makers make informed decisions, monitors a set of indicators to track a variety of community priorities in southeastern Louisiana such as disaster recovery, economic prosperity, and workforce development. A recent Data Center report, *The New Orleans Index at Ten: Measuring Greater New Orleans' Progress toward Prosperity* (Plyer, Shrinath, and Mack, 2015), looked at more than 30 indicators to examine New Orleans' progress toward prosperity and resilience in terms of the economy, inclusion, quality of life, and sustainability since Hurricane Katrina (Plyer, Shrinath, and Mack, 2015). Similarly, the Black Hills Knowledge Network's South Dakota Dashboard provides trend data in the form of charts, graphs, and maps that track community indicators such as civic engagement, demographics, the economy, health, housing, workforce, and income that communities can use for strategic planning and policy making.[2] Information from these types of efforts could inform community resilience decision making and programs.

In addition to tracking community indicators, communities are increasingly required to monitor change across various dimensions of urban systems. This often entails developing plans, tracking progress, and adjusting strategies to achieve goals, all of which can influence resilience. In fact, increasingly, federal agencies are requiring communities and regions to adopt certain plans to be eligible for federal funds: The Department of Transportation requires transportation plans (FTA, n.d.), the Department of Housing and Urban Development requires consolidated plans for affordable housing (HUD Exchange, n.d.), and the Environmental Protection Agency requires stormwater management plans (NPDES, n.d.). For example, FEMA requires communities to develop mitigation plans to be eligible for pre- and post-disaster funding under the Disaster Mitigation Act; a key requirement of these mitigation plans is to monitor and track plan performance. States often require local comprehensive plans, and some states (e.g., California and North Carolina) require that these comprehensive plans incorporate hazard mitigation elements. To be eligible for funding, communities must regularly update these plans, monitor performance, and show progress in achieving goals (Berke et al., 2018).

[2] For more information visit the South Dakota Dashboard website: https://www.southdakotadashboard.org.

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Challenges in Measuring Community Resilience

Community stakeholders shared that they are collecting data and tracking a variety of community indicators to support community operations and oversight of governmental activities. Some of these data and information may be useful in examining resilience *building*, but often do not assist in measuring *progress* in achieving resilience over time. Infrastructure-related activities typically receive the most attention and examination because data related to such efforts provide lifeline information for communities. Less likely to be found among the efforts being tracked are measures that relate to a community's ability to respond to and recover from disasters and other disruptions.

The communities discussed a few challenges related to measuring resilience: (1) taking into account all shocks and stressors, acute as well as chronic, (2) issues around data, and (3) scalability. Community stakeholders expressed a need for resilience measures that consider acute and chronic shocks and stressors. For example, one public sector official articulated that strategies to strengthen the science of measuring community resilience should cross disciplinary and jurisdictional boundaries to address common hazards as well as acute and chronic stressors associated with disasters and disparities; current measurement tools do not align easily with this.

Several communities discussed challenges associated with data. Among the various organizations in a community, there are a multitude of data types and data sources, different platforms, and different systems. This diversity of data and systems can make it difficult for communities to undertake resilience planning and measurement that extend beyond a single organization, sector, or municipality. For example, data collection efforts within and across counties lack coordination among jurisdictions, and data are under-utilized by local decision makers. ***Finding 3.3.*** **Community organizations often have their own data sources, systems, tools, and platforms that are not compatible with those of other organizations, making it difficult to integrate measurement activities across sectors.**

Another challenge revolved around data availability: quality and quantity of data, update cycles of data, and spatial reference of the data (e.g., parcel, block, neighborhood). For example, census data are readily available at the tract level or block level in cities but are either not available at a finer scale for communities with smaller populations or are accompanied by estimation uncertainties.

RESILIENCE THEMES ACROSS COMMUNITIES

Through discussions with community stakeholders, four common themes emerged across the communities about community resilience-building and challenges: (1) community engagement and buy-in are important, (2) community resilience has multiple dimensions, (3) decision makers need to be able to justify resilience investments, and (4) resilience should provide multiple benefits. The

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committee recognizes that these common themes were identified from a small sample of eight communities; still, these themes align with the experiences of other communities in which the committee members have worked or conducted research and those described in the literature (see Chapter 2).

Community Engagement and Buy-in Are Important

A common theme across the communities visited was the importance of community engagement and buy-in, as well as buy-in from leadership within local government. Community engagement is important for building relationships and trust between community leaders and members, coming to an agreement on a shared vision and goals, and successfully implementing actions to achieve those goals (De Weger et al., 2018; Martiskainen, 2017; Pigg, 1999; Ricketts, 2009; Ricketts and Place, 2009). Community engagement can include a variety of elements such as networks, multistakeholder partnerships, leadership, and communication. In communities that have made progress on their resilience strategies, community stakeholders and members understand and agree on their common risks, goals, and priorities within the context of different community capitals (e.g., natural, built, financial, human, social, and political). ***Finding 3.4*. Community engagement and buy-in are critical to community resilience.**

Local governments are reaching out more to engage their community members. However, community engagement is a two-way communication process: Local government needs to demonstrate that it uses the feedback to inform or change its actions. Though it can be difficult for a community to change its standard community engagement process and broaden it to include other stakeholders, participation and feedback from diverse stakeholders and community members is essential to make resilience a priority and to determine the risks and goals of the entire community (De Weger et al., 2018; Jennings, 2009; Talò, 2018; Wells et al., 2013).

For resilience activities or efforts to succeed, community stakeholders stressed that all stakeholders involved in resilience-building initiatives need to recognize the risks the community faces and jointly identify and develop actions to mitigate those risks. Communication outreach programs about resilience can be built into broader community engagement efforts. For example, in preparation of its proposal for HUD's Community Development Block Grant-National Disaster Resilience competition, Minot's local government held 60 public meetings with diverse community members. The city won a $74 million HUD grant in 2016 and has strong community support for the city's resilience efforts. Community stakeholders noted that their programs to assist residents in learning about resilience and its challenges are more likely to succeed than programs in communities that only have a few people familiar with the concept. In some cases, communities understand their risks and choose to accept those risks rather than take

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action to manage them. For example, local government may decide to roll back requirements to mitigate against specific risks or hazards if it is too expensive or negatively impacts community functions (e.g., people or businesses may decide to move out of a community if certain regulations are imposed).

Stakeholders across the communities emphasized the importance of building multistakeholder relationships and trusted networks. Nonprofit organizations shared approaches for creating and forming strong partnerships and leveraging each other's resources to help clients in need. For example, the Greater Baton Rouge Food Bank partners with more than 115 agencies, and these partnerships are an essential part of its food dissemination activities.[3] In Cedar Rapids, the Linn Area Partners Active in Disasters is a coalition of over 45 organizations that work together to address disaster recovery needs through information sharing, advocacy for those who are most vulnerable, and simplifying access to services (LAP-AID, n.d.).

Figuring out how to get leadership engaged is an important part of community engagement, as well as a challenge for many of the communities. Similarly, the loss of a leader who played a strong role in resilience practice can encumber resilience plans and projects, even after a successor takes over. Community champions, when present, can provide vital support for resilience efforts and keep the community moving forward. When these individuals are trusted by the community, local governments can partner with them to help prioritize resilience goals and put resilience efforts into action.

Two of the communities visited, New Orleans and New York City, are members of the Rockefeller 100 Resilient Cities initiative and have resilience leaders called chief resilience officers—people charged with developing a city's resilience strategy. One year after New Orleans published its resilience strategy, more than 75 percent of the actions outlined in the strategy were completed or under way (City of New Orleans, 2016). In 2016, New Orleans received $141 million as part of the National Disaster Resilience Competition funded by the Department of Housing and Urban Development. The New Orleans proposal, "Reshaping the Urban Delta," called for the creation of a comprehensive resilience district in Gentilly with projects that invest in innovative and creative solutions so that the people, culture, and infrastructure can thrive (City of New Orleans, n.d.).

Three years after New York published its resilience strategy, the city has made significant strides toward its resilience goals, seeing an increase in affordable housing, a decrease in unemployment, divestment of pension funds from fossil fuel companies, and the launching of a heat mitigation and adaptation program (City of New York, 2018). In both New Orleans and New York, the efforts of the chief resilience officer in developing a resilience strategy helped provide a roadmap for moving resilience forward in the communities.

[3] For more information about the Greater Baton Rouge Food Bank, visit https://brfoodbank.org.

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The Multiple Dimensions of Community Resilience

Disaster recovery and infrastructure are often stimuli for resilience discussions, but communities shared that they view community resilience across multiple dimensions of the community (e.g., physical, natural, social, human, financial, and political) and a broad range of approaches (e.g., sustainability, strategic planning, disaster management, public health, and adaptation). Community resilience also cuts across chronic and acute shocks and stressors, and across multiple scales (neighborhood, city, county, etc.). ***Finding 3.5*. Resilience is multidimensional.**

Many community stakeholders highlighted the importance of addressing not only their risks to specific disasters such as hurricanes, wildfires, and floods, but also addressing existing community stressors. Communities noted how chronic stressors, such as poverty and crime, affect the building and maintenance of a resilient community. Building community resilience can be very difficult for people who are dealing with day-to-day stresses (e.g., drugs, violence, homelessness). Community stakeholders found it challenging to identify how to measure some indicators of vulnerability (e.g., inequality, access to services, equity) of at-risk populations.

Communities shared that resilience-building cuts across multiple scales and they recognize that local resilience is tied to regional resilience; planning at the regional level is important. The resilience of outside entities (e.g., other communities, county, region, state) can substantially impact local resilience. In Louisiana, the LASAFE initiative was designed around both acute and chronic stressors and is an example of a cross-sectoral approach and model of how to advance the practice of community resilience (NOPR, 2018). A combination of nonprofit, government, and private partners with decision-making authority lead the program in order to achieve a vision of a more vibrant and resilient future. It uses a cross-sectoral planning process and community engagement to address a wide array of local resilience challenges in parishes across the state. Specifically, it identifies community assets that can be used to more effectively adapt coastal communities to a new future and provides funding for 10 projects that are tackling flooding and land loss in six high-risk coastal parishes.

Need for Decision Makers to Justify Resilience Investments

Decision makers make difficult funding choices among competing priorities. Local governments with limited funding are under pressure to prioritize only a subset of the actions necessary for broad community resilience, for example, short-term, day-to-day community priorities such as inadequate infrastructure or those associated with community stressors such as crime and poverty. The inability to judge the return on investment or the benefits associated with resilience projects makes it difficult to justify investing more comprehensively in resilience. ***Finding 3.6*. Decision makers struggle to determine where resilience investments should be made and what benefits to expect from those investments.**

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In addition, community leaders who operate at the forefront of resilience lack operational metrics and management tools to document, monitor, and track the short- and long-term direct benefits—let alone indirect or intangible benefits—emanating from complex, multidimensional resilience endeavors. If communities are not using specific tools or frameworks to measure their resilience, it is difficult for them to justify decisions to fund resilience projects, to show project impacts, or to demonstrate the benefits of their resilience projects. As a result, communities do not feel fully informed to invest in resilience and/or use resilience metrics.

Resilience Should Provide Multiple Benefits

Communities expressed that their staff and resources are often overextended, resulting in resilience-building activities taking a backseat to addressing day-to-day issues. Many agencies and organizations already have too many line items to deal with in their budgets. In order for communities to undertake resilience activities, these activities need to be "baked into" already existing programs and processes, affiliated with existing budgets and authorities, and aligned with other community initiatives. For example, communities could integrate resilience into current planning efforts (e.g., emergency management, public works, urban planning, land use planning, hazard mitigation, transportation), neighborhood and public health initiatives, and infrastructure projects. ***Finding 3.7*. Communities are better able to pursue resilience-building efforts when those efforts align with other community initiatives and provide multiple community benefits.**

Even though pre-disaster actions are known to be cost-effective (Multihazard Mitigation Council, 2017), community stakeholders recognize that they are investing less in these actions than is needed. Certain resilience activities can be undertaken without significant new investment simply by integrating resilience goals into day-to-day operations (Berke et al., 2015; Gilbert et al., 2015). For example, improving local codes and standards for new construction in order to increase infrastructure resilience could be mainstreamed for any community. In other words, community stakeholders viewed community resilience measurement as a continuous process that should be embedded in day-to-day practice rather than a one-time assessment in the aftermath of a disaster. Community stakeholders seek tools that assess the impact of resilience work and track resilience investments in order to show that the investments are working.

Multiple benefits were commonly discussed within the context of mitigation investments and the activities of grassroots neighborhood organizations. For example, in Cedar Rapids, the McGrath Amphitheatre, located on the Cedar River, serves as a community gathering space for outdoor concerts and events and was built as part of the city's flood protection system, as it is used as floodwater storage during inundation events (City of Cedar Rapids, n.d.).

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CONCLUSION

There are many frameworks and tools available to communities that purport to measure community resilience, though none of these is a silver bullet for resilience measurement (Chapter 2). Yet many communities lack the resources (e.g., time, staff, funds) to implement resilience measurement and do not devote resources to explicitly measure resilience. In fact, all the resilience measurement efforts discussed in this report were underwritten and/or implemented in communities by outside entities (e.g., 100 Resilient Cities, National Institute of Standards and Technology, Resilient America Program), suggesting that many communities need a catalyst to help them with resilience building and measurement. The Gulf Research Program has an opportunity to be this catalyst in the Gulf region, and Chapter 5 provides a framework to support the GRP's efforts to accomplish this.

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4

For Communities: Actions for Building and Measuring Community Resilience

BOX 4-1
Chapter 4 Findings and Recommendations

Finding 4.1 Relevant information or data from disparate programs could be linked with each other and to community resilience priorities to position resilience in the context of existing efforts and priorities.

Finding 4.2 Investments should consider choices and tradeoffs that account for a range of stressors and short- and long-term gains, and those gains can be tracked along or across multiple sectors.

Finding 4.3 Financial tools can support resilience building and measurement.

Finding 4.4 Measuring multiple benefits of community resilience investments can be connected to existing financial and insurance structures because they require and incentivize quantitative measures of resilience.

Recommendation 1. Communities should use community participation and engagement at the outset of their resilience building and measurement efforts.

Recommendation 2. Communities should design and measure resilience around multiple dimensions of a community.

Recommendation 3. Communities should ensure that the data collected, integrated, or synthesized for community resilience are relatable and usable for decision making.

Recommendation 4. Communities should incentivize the measurement of resilience.

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The National Research Council (NRC) 2012 report *Disaster Resilience: A National Imperative* highlighted the need for "measuring progress toward resilience" and suggested the adoption of a "uniform . . . resilience scorecard" (NRC, 2012). In the years since that report was published, research has evolved from a uniform strategy for measuring resilience toward a portfolio of measurement tools that can more accurately assess a community's unique risk profile, assets, needs, priorities, and social determinants. This tailored approach toward resilience measurement is aimed at facilitating a more realistic assessment of a community's baseline conditions, as well as a more feasible set of desired outcomes and, in turn, a selection of measures that more accurately captures progress toward achieving resilience goals.

Charge 5 of this study's Statement of Task (see Box 1-2) focuses on identifying common approaches to measuring community resilience and ways to overcome challenges related to those approaches. Based on the findings of Chapters 2 and 3, this chapter addresses that charge by outlining four actions that communities can use to ensure that their resilience programs and measurement work align with their resilience priorities and achieve their resilience goals (see findings and recommendations in Box 4-1).

During the community site visits, local stakeholders expressed uncertainty about what they should measure, what measures to use, or even how to start the resilience-building process. The large number of resilience measurement efforts available (Chapter 2) and the paucity of use of those tools (Finding 3.1) reveal a gap between research on and the implementation of resilience measures. This chapter provides four key actions that communities can take to bridge this gap and help them move from building resilience to measuring it. Communities should:

1. Build community engagement and buy-in,
2. Account for communities' multiple dimensions,
3. Link community resilience measures to decision making, and
4. Create incentives for measuring resilience.

BUILD COMMUNITY ENGAGEMENT AND BUY-IN

Community engagement and buy-in are critical for establishing resilience goals and priorities (Finding 3.4). Some of the major functions of the community engagement process are to set resilience goals, prioritize those goals, and identify community leaders to champion resilience and implement actions aimed at meeting those goals. Community engagement also builds and strengthens social capital.

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Models of Community Engagement

The International Association of Public Participation defined several levels of community engagement—from a nonbinding, passive level of obtaining feedback to full empowerment where decision making lies solely in the hands of a community (IAP2, 2000). Other known models of community engagement have also been documented. For example, Minkler and Wallerstein (2008) outlined principles of community-based participatory research, several of which apply to measuring community resilience such as the notion that the community is the unit of analysis and participatory decision making is an iterative, cyclical process that supports the overall goal of building long-term resilience. However, when these original community-based participatory research principles published by Minkler and Wallerstein (2008) were applied post-Hurricane Katrina in Louisiana, the impact of the disaster, often exacerbated by concomitant chronic stressors such as historic burdens of health disparities, was shown to decrease a community's capacity to maximally engage even years later (Lichtveld et al., 2016). Citizen-engaged science (Finn and O'Fallon, 2017) has as its hallmark the use of community-generated data and information and may also be a useful strategy to measuring community resilience.

Community engagement is important in developing feasible goals and setting realistic priorities. For example, the National Institute of Standards and Technology's 2016 Community Resilience Planning Guide for Buildings and Infrastructure Systems relies on a collaborative planning team representing the interest of all public and private stakeholders in the community to explicitly use priority setting and resource allocation as the basis for its approach for community resilience planning. It is also important to work with community members to determine milestones that are sensible for the community's needs and context and to link measures to those milestones that will help track that progress accordingly. Setting resilience goals and priorities is necessary before any measurement activities take place. They provide the basis against which progress can be tracked and success can be gauged.

Leadership

An important element of community engagement and buy-in is to identify community leaders who will champion resilience, implement resilience goals, and coordinate resilience measurement. The Rockefeller Foundation's 100 Resilient Cities initiative, for example, places strong emphasis on leadership. In each of the designated resilient cities, the 100 Resilient Cities grant supports a full-time chief resilience officer who is tasked with carrying out and leading the community's resilience efforts, serving as a focal point for cross-sector collaboration and community-engaged monitoring of implementing priorities and achieving goals (see Box 4-2). The 100 Resilient Cities model (Arup, 2015) for centralized leadership has inspired many cities, counties, regions, and private organizations to

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BOX 4-2
What Is a 100 Resilient Cities Chief Resilience Officer?

A chief resilience officer (CRO) is a top-level advisor that reports directly to the city mayor. This person's task is to establish a compelling resilience vision for the city, working across departments and with the local community to maximize innovation and minimize the impact of unforeseen events.

CROs in the 100 Resilient Cities initiative demonstrate:

- "**Leadership:** CRO must be able to inspire, influence, and enlist colleagues and city residents to activate the city's resilience strategy.
- **Ability to engage locally:** CRO must understand their community and local setting and be able to establish and maintain strong engagement from municipal leader, city residents, and key stakeholders.
- **Ability to function across disciplines:** CRO must be able to communicate with and be effective within multiple sectors and disciplines such as transportation, energy, healthcare, housing, education, and community engagement."

Other skills of a CRO include the ability to engage globally, an enterprising spirit, effective communication, and project management skills.

SOURCE: Salkin, 2014.

create a chief resilience officer–type position. For example, Charleston, SC—not one of the 100 Resilient Cities—created and self-funded such a position in the mayor's office to carry out its resilience work and activities (Darlington, 2017).

Whether the leader is formally selected as a chief resilience officer or a similar position, communities can designate resilience leaders from within to implement measurement efforts, including tracking and monitoring community resilience progress. In addition to designated resilience leaders, trained community leaders can provide guidance to more efficiently link resilience measurement with community priorities. Leaders can facilitate the use of resilience measurement in community design, policy, and program development to track progress toward meeting those priorities. For example, in the Los Angeles County Community Disaster Resilience Project (Plough et al., 2013; Wells et al., 2013; Williams et al., 2018), local neighborhood coalitions were trained in various aspects of building and measuring resilience capacity, including the use of tabletop and other evaluative exercises (Chandra et al., 2015).

Community engagement is the first step in building and measuring community resilience. An engaged community, supported by a trained community leader, can set feasible goals, identify realistic priorities, and implement a tailored set of measures to assess progress toward sustainable resilience.

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ACCOUNT FOR COMMUNITIES' MULTIPLE DIMENSIONS

Resilience is multidimensional, cutting across multiple community capitals (Finding 3.5). Six community capitals or dimensions—natural (or environmental), built (infrastructure), financial (economic), social, human and cultural, and political (institutional or governance)—are relevant to a community's ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events. The need for and benefits of including multiple dimensions of a community in resilience actions are well documented (see Chapter 2). The measurement of resilience should reflect multidimensionality in terms of data collection, analysis, integration, translation, and dissemination.

A community's capacity to use a multidimensional approach depends on the expertise of its stakeholders and the diversity of the community members engaged in the resilience process. Academic partners can play an important role in the data collection and analysis related to community resilience. For example, in New Orleans, the city's Department of Health partnered with Tulane University School of Public Health and Tropical Medicine's Disaster Management Program to strengthen its disaster response workforce capacity, hire competent leaders specialized in disaster management, strengthen the implementation of the city's special needs registry, and advance its disaster communication enterprise.

Community leaders and the literature extol the value and import of multidimensional approaches to community resilience, but they acknowledge that measuring or collecting data across multiple dimensions is daunting. Typically, community programs and policies account for one capital (e.g., built/infrastructure) and/or peril (e.g., flood risk) at a time, which makes it difficult to characterize or measure resilience across the different community dimensions. Most often, community resilience efforts emphasize built capital such as buildings, roadways, communication infrastructure, and utilities (Aldrich, 2012; Aldrich and Meyer, 2015).

The human and social dimensions of community resilience—such as the strength of social networks, the efficiency and effectiveness of governance, and social capital—are well-established elements of resilience, but are rarely assessed and measured in ways that align and complement the data collected in the built or natural dimensions (Aldrich and Meyer, 2015; Varda, 2011). Public health data are an important exception. The Centers for Disease Control and Prevention as well as many state and local health departments collect and analyze data to assess provision of essential public health services. Essential public health services focus on assessment (e.g., monitor health, diagnose, and investigate), policy development (e.g., inform, educate, and empower; mobilize community partnerships; develop policies); and assurance (e.g., enforce laws, link to/provide care, assure competent workforce, evaluate) (CDC, 2017).

The good news is that there are options to better integrate information across this variety of existing data sources and community capitals. Disaster management and emergency preparedness data sets from federal agencies can provide a

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wealth of information for the measurement of resilience. Many federal government programs require some type of application process and indicators of success or desired outcomes (e.g., the Federal Emergency Management Agency's Hazard Mitigation Grant Program and Public Assistance Grant Program, the Department of Housing and Urban Development's Community Development Block Grants, and the Small Business Administration's Disaster Loan Assistance). Such outcomes could align with resilience goals or priorities. Criteria and information gathered in these application processes, especially the Federal Emergency Management Agency's community rating system, could also be used in a community resilience function. If information from these programs were linked with each other and to community resilience priorities, it could reveal the status of a community's resilience capacity in terms of a broader range of stresses such as economic difficulties, housing shortages or homelessness, slow moving impacts of climate change, or even the legacy effects of community or historical trauma.

***Finding 4.1*. Relevant information or data from disparate programs could be linked with each other and to community resilience priorities to position resilience in the context of existing efforts and priorities.**

LINK COMMUNITY RESILIENCE MEASURES TO DECISION MAKING

Information about resilience capacities and capabilities should inform policy formulation and implementation and choices about public sector budgets and public-private financing. Most local governments conduct community assessments to inform local decision-making; the challenge is to more fully embed resilience measurement in that process. Building from assessments already occurring at the community level creates opportunities to generate measures in multiple capitals. Policy makers and other stakeholders faced with making challenging trade-offs regarding human and financial resource investments need integrated data and information related to both acute and chronic stressors encountered by communities (Hall et al., 2012).

Data and information can be integrated across the multiple community dimensions through stronger connections with community goals and plans (e.g., community business plans and disaster preparedness plans) (Godschalk et al., 1998; NIST, 2016). For example, linking existing land use planning regulations, building codes, or standards with community goals could show ways that existing data could be used for different, useful purposes (Chandra et al., 2011; NIST, 2016). Such alignment would further connect the structural, social, and natural systems that underlie a community's functions (Fung and Helgeson, 2017) in ways that would allow single actions to provide positive results in more than one capital, policy, or program dimension.

Rodin (2014) refers to multiple benefits as the "resilience dividend," and the National Institute of Standards and Technology provides an expanded version of

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the concept (see Box 4-3). A conceptual model, called the Resilience Dividend Valuation Model (Bond et al., 2017a,b), calculates the resilience dividend. The model supports decision makers who wish to quantify the value of resilience investments through a framework of costs, benefits, and co-benefits (see Box 4-4). The valuation model was developed with prior case examples and is starting to be implemented in other contexts (Bond et al., 2017a).

Resilience is premised on the idea that investments consider choices and tradeoffs that account for a range of stressors and short- and long-term gains (Bond et al., 2017a,b) and that those gains can be tracked along or across multiple sectors. For example, meeting the affordable housing needs of a community with buildings that can withstand hazard events and allow residents to shelter in place can mitigate chronic housing challenges, reduce post-event demand for shelters, and/or accelerate the availability of a local workforce. Community resilience measurement needs to include a range of downstream or cascading impacts of investment choices to capture the broadest range of multiple benefits. Downstream effects can be ascertained through longitudinal assessment, since resilience investments may produce returns and co-benefits that are valuable to the community over time. Valuation models, such as the Resilience Dividend Valuation Model framework, account for iterative steps, involve adaptive interventions, show potential for long-term evaluation or measurement, and demonstrate ways to link data with decision making.

Finding 4.2. **Investments should consider choices and tradeoffs that account for a range of stressors and short- and long-term gains, and those gains can be tracked along or across multiple sectors.**

BOX 4-3
National Institute of Standards and Technology: Defining the Resilience Dividend

The resilience dividend is the net benefit (or cost) that accrues from investments aimed at increasing resilience, in the absence of a disruptive incident over the planning horizon. The premise is "that investments in financing and resourcing long-term resilience may yield short-term economic benefits. The purpose of articulating and measuring the resilience dividend is to make co-benefits of resilience planning tangible. In this way, decision makers are less likely to undervalue resilience-related investments. This may include assigning value and considering co-benefits such as increased jobs and enhanced reliability of an infrastructure system, which improve the community even in the absence of a disruptive incident" (Fung and Helgeson, 2017, 2).

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BOX 4-4
The Resilience Dividend Valuation Model Approach

The Rockefeller Foundation and the RAND Corporation developed the Resilience Dividend Valuation Model, a tool that allows communities, practitioners, and decision makers to quantify the value of resilience investments using a resilience dividend (see Box 4-3) (Bond et al., 2017a,b). This model provides a framework for assessing resilience interventions that ultimately create benefits and costs within a system, such as a community or city.

Defined as the difference between the net benefits to a society between a resilience-minded project and a business-as-usual (BAU) project, the resilience dividend can be calculated using the Resilience Dividend Valuation Model, which "maps changes in the flow of goods and services from a resilience project into changes in well-being, and provides guidance on the data needed to estimate the resilience dividend" (Rodin, 2014). It places considerable importance on the linkages between elements of a system that can be used to create additional co-benefits.

The six basic steps for applying the Resilience Dividend Valuation Model are (Bond et al., 2017b):

1. Define the resilience intervention and BAU scenarios,
2. Map the system,
3. Define the shocks and/or stressors,
4. Map out the changes to the system in the intervention and BAU scenarios,
5. Estimate the intervention and BAU paths, and
6. Aggregate the estimates of well-being.

Not a "black-box tool," the Resilience Dividend Valuation Model is a flexible approach that guides users in how to best use data to work toward calculating the resilience dividend.

CREATE INCENTIVES FOR MEASURING RESILIENCE THROUGH MULTIPLE BENEFITS

A formidable challenge in measuring resilience is that, on the surface, there are few incentives to do so. However, there are tangible benefits to building resilience, and measurement connects resilience actions to their dividends. Some communities are beginning to use novel approaches to incentivize resilience investments or demonstrate multiple benefits from resilience actions.

Risk reduction can be financed for resilience building, pre- or post-disaster. These financing options require quantitative measures of resilience because investors (public or private) often demand estimated returns prior to making their investments. These tools and measures focus on economic impacts as well as sometimes focusing on building economic and ecological resilience. Box 4-5

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BOX 4-5
The Nature Conservancy: Coastal Zone Management Trust

Coral reefs are essential for coastal protection—a healthy coral reef can reduce 26 percent of economic losses caused by hurricanes and storms. The Mesoamerican Reef is the longest barrier reef in the Western Hemisphere. It is home to some of the world's most important and unique coral reefs, mangrove forests, fish species, and marine mammals. The reef protects the most important tourism hub in Mexico, the Riviera Maya, which receives more than 10 million tourists per year and generates $10 billion annually. Since 1980, 80 percent of live coral cover in the Mexican Caribbean has been lost or degraded due to disease, bleaching events, diminishing herbivore populations, and algae overgrowth.

In 2018, The Nature Conservancy, Swiss Re, and the Mexican government announced a new type of insurance to protect coral reefs in Mexico as part of a broader Coastal Zone Management Trust. The trust and the new insurance product will help the conservation and swift restoration of the reef if damaged by a major hurricane, and support the economic resilience of the region.

Funds for the trust and subsequent insurance premiums will be collected as a portion of the tourism taxes and from other government sources. The trust will provide a suite of benefits that aim to strengthen the economic resilience of the region, encourage permanent conservation and restoration of the reef, and create a scalable new market for the insurance industry. Ultimately, this multistakeholder model could support other regions and ecosystems.

provides an example of the co-benefits of the Coastal Zone Management Trust for coral reefs in Mexico (Beck et al., 2018).

Currently, impact investing is at the forefront of the growing trend toward attracting private investment to conservation and other social benefits, and represents the largest class of investments that can support resilience building (Colgan, Beck, and Narayan, 2017). Impact investing refers to investments made into companies, organizations, and funds with the expectation that these investments will achieve social and environmental impacts as well as financial returns (GIIN, n.d.).

Green bonds, an example of impact investing, are financing options that aim to deliver environmental and financial benefits. The largest type of green bonds support projects designed to reduce greenhouse gas emissions and limit repercussions from climate change (CSG and MCBE, 2016; World Economic Forum, 2013). Green bonds, and impact bonds in general, have created significant pools of capital because they are well suited to the needs of certain types of investors who are looking for long-term, steady, and relatively low-risk investments (CSG and MCBE, 2016; The Economist, 2013).

Green bonds represent a form of investment in resilience building because they seek to reduce long-term climate risk. To become more widespread, green bonds need two core conditions: (1) a revenue source to repay bond buyers and

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(2) a set of performance standards to demonstrate attainment of risk reduction goals (Colgan, Beck, and Narayan, 2017). These performance standards require quantitative measurement, which can help create the incentives required for better measures of resilience—this means that new resilience financing can become available if its benefits can be quantitatively measured.

Another type of financial tool is a catastrophe bond, an insurance-linked security created for a specific place and a well-defined set of risks over a specific period of time, such as hurricane-related wind damage for a given hurricane season or seasons (Nowak and Romaniuk, 2013). The bond can be issued by any entity, including governments or private organizations. The bond buyer is paid a defined sum over the period of the bond; the interest payments on the bond are the equivalent of insurance premiums. The bond's proceeds are put in escrow for the term of the bond (usually 3 to 5 years), and if the pre-defined events occur, the bond is paid out. If the defined events do not occur, the bond proceeds are returned at the end of the term to the buyer (Alvarez, 2017; Jarzabkowski, Bednarek, and Spee, 2017).

An emerging idea is to create resilience bonds that use the differences in bond prices between the catastrophe bonds that are priced with specific risk-mitigating actions in place and those priced without such actions in place. These actions can be tasks or efforts related to community-resilience goals, programs, or policies. The savings from risk reduction would be reflected in the prices of catastrophe bonds, and those savings can then be diverted into risk-reducing or community-resilience projects (Vajjhala and Rhodes, 2015). The resilience bond concept is one example of an incentive for catastrophe bond buyers to divert a portion of the proceeds to meeting community resilience goals.

***Finding 4.3*. Financial tools can support resilience building and measurement.** New financial tools can support resilience building. These tools require (and thus incentivize) quantitative measures of resilience to track their effectiveness. Some of this operationalizing is already under way, as experts in the finance sector now parameterize resilience benefits as a basis of innovative financial tools from bonds to insurance.

***Finding 4.4*. Measuring multiple benefits of community resilience investments can be connected to existing financial and insurance structures because they require and incentivize quantitative measures of resilience.**

RECOMMENDATIONS FOR COMMUNITIES

There are many measurement tools, but none of them is a silver bullet for community resilience measurement (Chapter 2). Each community's pathway toward resilience is unique—there is no one-size-fits-all for building community resilience (Chapter 3). The measures that a community uses depend on the community's goals, and it is up to each community to figure out how to track or

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measure whether it is reaching its goals or how close it is at a given point in time. Resilience building does not equal the use of a specific measurement tool or set of resilience measurements. Rather, resilience building is a process that requires periodic measurement to assess progress toward resilience goals and ensure those goals are being met. This chapter presented four key actions that are needed for community resilience designs to result in measurable, achievable results. From these actions, the committee provides four recommendations that communities could follow to track and measure their resilience efforts.

Recommendation 1. **Communities should use community participation and engagement at the outset of their resilience building and measurement efforts.** Within a community, it is important to engage diverse stakeholders to identify and support leadership, data collection, and integration to track resilience measurements. The participatory process can facilitate goal setting and prioritization for community resilience, generate community buy-in for the goals and approaches, and identify people within the community who can be leaders, champions, implementers, or trainers. It also helps build and strengthen social capital within the community.

Recommendation 2. **Communities should design and measure resilience around multiple dimensions of a community.** Communities are comprised of multiple dimensions, most commonly captured by six capitals: natural, economic/financial, physical/built, social, human, and political. These capitals provide structure for setting community resilience goals and a reference for measurements that reflect progress toward communities' achievements.

Recommendation 3. **Communities should ensure that the data collected, integrated, or synthesized for community resilience are relatable and usable for decision making.** The data collected, integrated, or synthesized need to be relatable, usable, and ultimately used to make decisions or gauge the efficacy or progress of the communities' goals.

Recommendation 4. **Communities should incentivize the measurement of resilience.** Investments required to achieve community resilience goals should yield multiple benefits that are trackable along and across the relevant community capitals and with milestones over time.

It was clear to the committee through its community visits that communities are aware that they spend precious resources on collecting information in the different capitals and understand the importance of the four above actions in resilience design and measurement. But also emerging from the visits was a knowledge-to-action gap for building and measuring community resilience in

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governing organizations. Gaps remain in the application and implementation of comprehensive strategies for community resilience, and in linking goals and objectives with identification, planning, and assessment for one or a small set of risks. Communities can exercise at least two options to fill these gaps. One is for communities to have stronger connections among themselves to foster learning and exchange. Another is to position community decision makers alongside researchers in longitudinal research efforts that integrate research, data collection and assessment, and decision making with community resilience goals and priorities. Specific recommendations for the Gulf Research Program to fill the knowledge-to-action gap are outlined in Chapter 5.

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5

For the Gulf Research Program: Ways Forward for Building and Measuring Community Resilience in the Gulf Region

BOX 5-1
Chapter 5 Recommendations

Recommendation 5. The Gulf Research Program should develop a major, coordinated initiative around building or enhancing community resilience in communities across the Gulf region.

Recommendation 6. For each community in the Gulf Research Program (GRP) community resilience initiative, the GRP should develop and employ a community resilience framework that includes: (1) community engagement to engender buy-in around resilience priorities, goals, and leadership; (2) resilience across multiple community capitals; (3) measures and ways to track progress that are useful to decision makers; and (4) investments in resilience that result in multiple benefits.

Recommendation 7. The Gulf Research Program should create, finance, and maintain a resilience learning collaborative for diverse stakeholders to exchange information about lessons learned, approaches, challenges, and successes in their respective and collective work to advance community resilience in the Gulf region.

Recommendation 8. The Gulf Research Program should implement longitudinal research associated with its community resilience program.

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The final charge in the Statement of Task is to provide findings and recommendations on common approaches and "key issues for future programs to consider in measuring the resilience of a community" (see Box 1-2). The committee interpreted this charge as referring to future programs that the Gulf Research Program (GRP) would administer. This chapter makes specific recommendations for the GRP to design efforts around community resilience using a framework that measures and tracks progress in achieving community resilience goals (see Box 5-1).

The GRP has the mandate to effect change in the Gulf region backed by a $500 million endowment, on a 25-year timeline. The GRP possesses autonomy over how it exercises its mandate. The Gulf region provides the GRP a fertile landscape for building and measuring community resilience. The mix of assets related to economy, ecology, and a rich, diverse, and vibrant culture in the Gulf contrasted by intransigent disparities presents a portfolio of complex and often interconnected research questions that have remained unaddressed since the BP oil spill in 2010. The urgency for action is underscored by the persistent challenges faced by Gulf Coast communities: poor health indicators; structural social inequity; an extractive economy; perils related to hurricanes and inland and coastal flooding; continued shoreline losses; and impacts of a changing climate. Four recommended actions for the GRP are outlined in the sections below.

MAJOR, COORDINATED INITIATIVE TO BUILD RESILIENCE ACROSS THE GULF REGION

***Recommendation 5*. The Gulf Research Program should develop a major, coordinated initiative around building or enhancing community resilience in communities across the Gulf region.**

The lessons and common elements of the major resilience measurement programs reviewed in this report (Chapter 2) combined with the information gleaned from the community site visits and other programs (Chapter 3) suggest that there are benefits in community-level processes, including both existing practices and new ways of thinking about risk, resilience, and community priorities. These benefits include diverse stakeholder engagement; goals and the use of measures to gauge progress in achieving those goals; and resilience benefits across multiple community dimensions from incentivized actions (see Chapter 4).

The GRP has the structure, resources, and time to design, implement, and monitor a community resilience initiative to realize such benefits. It can include explicit resilience measures that track progress toward short-term and long-term milestones to address the urgency to build sustained resilience in the Gulf region. The GRP resilience initiative should include multiple communities across the Gulf region's five states and take a nested approach to (see Figure 5-1):

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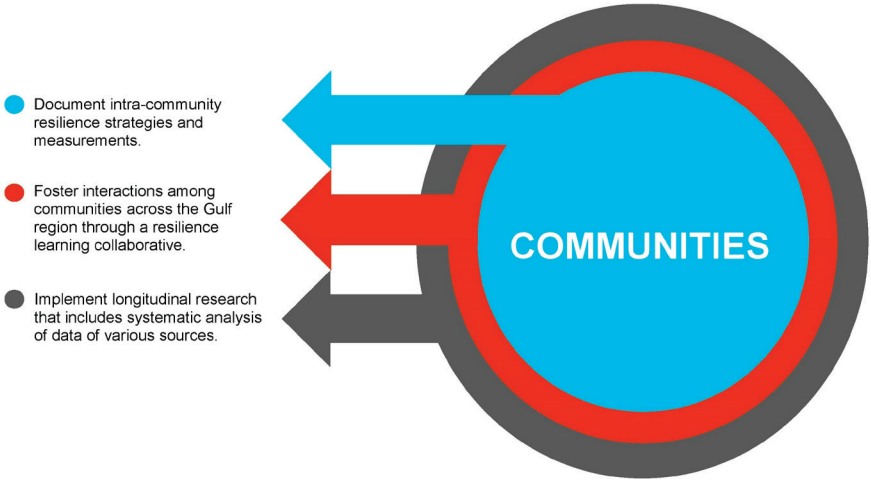

FIGURE 5-1 A GRP resilience initiative should include multiple communities across the Gulf region's five states and take a nested approach, operating at three levels: within a community, across communities, and over multiple years.

- Document the intracommunity resilience strategies and measurements within each of the selected GRP communities;
- Foster interactions across and among the selected GRP communities across the region through a resilience learning collaborative; and
- Implement longitudinal research that includes systematic analysis of data of various sources, including health metrics.

The GRP has the budget to undertake a community resilience initiative in the Gulf region. The exact budget for a community resilience initiative in the Gulf would depend on the number of communities involved and the scope of the initiative. The Rockefeller Foundation started in 2013 with an initial scoping budget of $100 million for 100 Resilient Cities, with the budget ultimately increasing to more than $164 million.[1] The Z Zurich Foundation's Flood Resilience Measurement Framework operated on a budget of $37 million over a 5-year timespan (Szönyi, 2017) and supported flood resilience measurement in over 110 communities, most in developing countries and many of those smaller villages. Therefore, based on other large multicommunity programs, the GRP's community resilience program in the Gulf Coast region should have an annual multimillion dollar budget over a minimum of 10 years.

[1] Otis Rolley of 100 Resilient Cities (100RC) shared this information with the committee during the community meeting with Rockefeller Foundation, 100RC, and Rebuild by Design in the New York City meeting in 2017.

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In addition, the committee recognizes that there continues to be a strong need for human health research in the Gulf region. Billions of dollars have been dedicated to research, cleanup, recovery, and restoration in the Gulf region following the 2010 Deepwater Horizon oil spill. However, despite initial human health research conducted in the aftermath of the disaster, there has been insufficient focus on human health research in the Gulf. Though this report has focused on building and measuring overall community resilience, the committee urges the GRP to develop an area of study centered on longitudinal human health research in the Gulf region.

A FRAMEWORK FOR COMMUNITY RESILIENCE

***Recommendation 6*. For each community in the Gulf Research Program community resilience initiative, the GRP should develop and employ a community resilience framework that includes: (1) community engagement to engender buy-in around resilience priorities, goals, and leadership; (2) resilience across multiple community capitals; (3) measures and ways to track progress that are useful to decision makers; and (4) investments in resilience that result in multiple benefits.**

Four key elements of building—and thus measuring—community resilience emerge (Chapter 4) from existing resilience programs and research (Chapter 2) and lessons learned from the community site visits (Chapter 3). For the purposes of the GRP, there are specific actions related to these four elements in order for a framework and community resilience initiative to take shape, for measurement approaches to be implemented and used, and to document the degree to which community resilience is being built. There is not a one-size-fits-all-approach to resilience practice or measurement (Finding 3.2). Therefore, the GRP community resilience initiative needs to account for community-level differences, and the GRP will need to consider how to contend with the likelihood that each community within its community resilience initiative may take different approaches, identify different priorities, and require different types of resources.

Community Engagement

Community engagement and buy-in are critical to community resilience (Finding 3.4). The GRP should use well-established and culturally sensitive community engagement practices to involve diverse perspectives and stakeholders from the public, private, nongovernmental, academic, and other sectors of a given location. In the Gulf region, and considering the mandate of the GRP, the participation of business and industry stakeholders together with a focus on the inclusion of diverse cultures and communities is a prerequisite to success. Through participatory methods such as facilitated discussions, focus groups, and key informant interviews, the GRP could elicit and co-develop important priorities

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and goals for resilience in each community. Essential outcomes of a community engagement approach would be the collective establishment of resilience goals or priorities and recruitment of a local leader(s) to champion the community resilience efforts. Collaborating with communities in these ways will require building trust and engaging factions of a community that may not normally work together. In addition, the GRP should continue its practice of embedding researchers in communities with local leaders, and it could expand its policy fellowship program to place fellows in communities engaged in resilience building and measurement efforts. Community engagement can take years and requires sustained commitment to each community. Community engagement and buy-in can help to ensure that the community's resilience approach, investments, and priorities will reflect the wellbeing and interests of the whole community across multiple community capitals, be sustained over time, and achieve additional benefits and outcomes beyond the direct program investments by the GRP.

Action: **In each of the GRP communities, the GRP should engage diverse stakeholders to build community buy-in around community resilience goals or priorities and recruit local leaders and champions for resilience efforts.**

Multiple Capitals or Dimensions of Community Resilience

Resilience is multidimensional (Finding 3.5), and at least six dimensions or capitals are relevant to community resilience. The natural, built/physical, social, financial, human, and political dimensions of a community are the six capitals most commonly identified in the community resilience literature (Chapter 2; Arup, 2015; NIST, 2016; Szoenyi et al., 2016; Zurich, n.d.). Traditional community engagement processes are easily adapted to ensure that multiple capitals are included in stakeholder discussions and interactive activities. The more diverse the stakeholders gathered and the greater the number of sectors involved, the more likely that multiple capitals will be considered in community resilience designs.

The multiple capital framework allows stand-alone efforts to connect with and feed data and information into an overarching community resilience framework. For example, the Coastal Zone Management Project in Mexico (see Box 4-5) shows how a single priority of protecting the coastal zone provided measurable benefits across economic, natural, and social capitals. While some communities plan across multiple sectors or collect data or information across different capitals, few measure resilience across different capitals (Finding 2.1). The GRP is poised to fill this gap and draw on the lessons learned thus far. It can be deliberate in designing and co-developing its resilience work to include all or as many capitals as possible as it collaborates with communities to measure and track their community resilience efforts.

Action: **As the GRP collaborates with communities to build community resilience, it should explicitly include as many of the community capitals as possible to capture how communities conceive their resilience priorities,**

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approaches, investments, and assessments. The GRP should also provide resources to support local leadership in their resilience-building efforts, for example, by embedding researchers into local communities to work with decision makers and other community stakeholders.

Evidence-based Information Useful to Decision Makers

As the GRP builds a community resilience portfolio, the initiative should be explicit about how resilience measures will be or could be used by community decision makers, including those in government, industry, and nonprofit sectors as well as those who represent land grant universities and other institutions in the Gulf that can actively contribute to long-term research and analysis.

One way to do this is to involve decision makers and other community stakeholders in the development of community resilience goals and priorities and actions needed to achieve those goals. The stakeholders could identify resilience measures needed to track progress of those goals. As those measures are collected and documented, the GRP could help design and generate evidence-based approaches for relating resilience measures to goals, policies, and programs. Community decision makers can more easily pursue resilience investments when those investments align with existing budgets and community initiatives (Finding 3.7).

***Action*: The GRP should be deliberate in bringing researchers and decision makers together in the community resilience process.** In doing so, the GRP can build the capacity of decision makers to incorporate data, information, and measurement in their policies, actions, and interventions. Simultaneously, the GRP can advance resilience measurement methods by which data collection, analysis, and application can be used in the complex contexts in which policy, programmatic, and budget decisions are made.

Investments that Yield Multiple Benefits

The Gulf region faces many risks: natural hazards or technological accidents, chronic conditions related to disparities and environmental degradation, and other risks that are the outcomes of slow onset events such as sea level rise, climate change, or shifts in the energy/oil and gas industries. There are tangible benefits to building resilience and financial tools that can support resilience (Finding 4.3). The GRP can derive viable community resilience strategies for the Gulf region from existing examples (e.g., see Box 4-5, Coastal Zone Management Trust). Private investment represents the largest class of investments that could support resilience building through impact investing tools like catastrophe, green, or resilience bonds (Colgan, Beck, and Narayan, 2017). The GRP's financial portfolio positions the program to participate in innovative, matching, and other investment approaches.

The GRP should establish ways to track or measure benefits across multiple capitals in ways that account for gains over the short term for current decision

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makers, as well as over the long term to examine changing and cascading or compounding impacts of investment choices. Decision makers struggle to determine where resilience investments should be targeted and what benefits they can expect from those investments (Finding 3.6). Valuation models show potential for long-term evaluation or measurement (Chapter 4), and nascent frameworks could provide the GRP a real-time laboratory to test ways to quantify resilience—its processes, outcomes, and effects (e.g., see Box 4-4, the Resilience Dividend Valuation Model).

***Action*: The GRP should guide short-term investments that will yield positive long-term benefits across multiple capitals.**

Summary of the Community Resilience Initiative

The GRP has the time and the financial resources to invest in a community resilience program. Such a program could: (1) test and document how and to what degree community resilience can be built or enhanced; (2) explore ways to address gaps in practical and research efforts thus far; (3) develop new or test existing frameworks for measuring and tracking resilience in communities across multiple capitals and over time; and (4) demonstrate a return on investment, best practices, and recommendations for prioritizing resources to build community resilience.

In creating the framework for community resilience to build and measure resilience within communities, the GRP should do the following:

1. Build a community resilience initiative through collaboration with multiple and varied communities across the Gulf region.
2. Engage stakeholders in each community from different sectors, with different perspectives, roles and responsibilities, economic status, ethnicities, age, and other professional and demographic markers.
3. Use the community engagement process to identify resilience goals and priorities for each community in the GRP initiative, allowing for local leaders and champions to emerge and for goals to be understood across multiple community capitals.
4. Link resilience goals and priorities with actions that decision makers take and with milestones for achieving those goals.
5. Foster investments that achieve community resilience goals while also providing benefits across multiple capitals.

LEARNING COLLABORATIVE FOR RESILIENCE

***Recommendation 7.* The Gulf Research Program should create, finance, and maintain a resilience learning collaborative for diverse stakeholders to exchange information about lessons learned, approaches, challenges, and**

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successes in their respective and collective work to advance community resilience in the Gulf region. Community stakeholders shared an overarching perspective with the committee: Every community has a challenge, strategy, approach, or lesson to share and knows that there is more to learn. Communities experience common challenges associated with budget, capacity, or time. The communities that participated in this consensus study showed a great range of innovation, creativity, and grit in approaching their problems and designing resilience solutions. Their openness in meeting and sharing their experiences and insights with the committee underscored the need for a learning collaborative to exchange ideas and share solutions. The participants in a learning collaborative should include government (local, state, federal levels), industry, academia, and other organizations engaged in community resilience efforts in the states of the Gulf of Mexico.

Some of the resilience programs discussed in this report (e.g., 100 Resilient Cities, Resilient America Program, the Zurich Flood Resilience Program, and the National Institute of Standards and Technology Community Resilience Program) bring their cohorts together for collaborative learning. These gatherings are often closed to outside groups or are by invitation only. Another example of a learning collaborative, while not resilience-related, is the National Climate Assessment Sustained Assessment program.[2] This program facilitated participation of scientists and stakeholders across regions and sectors and provided ongoing engagement among participating organizations. For communities not involved with these types of programs, opportunities are scarce to participate in a collaborative, open exchange of ideas and solutions. Therefore, among communities and decision makers, there is a lack of coordination, exchange, co-creation, and collaboration, even though the desire and need for this kind of forum are high.

A learning collaborative engenders cross-community learning and capacity building (Lasker and Weiss, 2003). The GRP is ideally positioned to create such a community resilience learning collaborative in the Gulf of Mexico region. With a learning collaborative at a regional scale, the GRP could create opportunities for learning and exchange, and solidly advance participatory research for the next generation of community resilience research and practice. Collaborative learning would allow the GRP to capitalize on interaction across and among the network of GRP resilient communities in the program, coordinate with other academic and nonprofit organizations active in community resilience, and test whether or how a regional approach to resilience in the Gulf could be realized from multiple, community-scale efforts. The GRP could play a convening role across at least two groups of vested stakeholders: the communities involved in the GRP community resilience initiative and other groups that also received funds from settlements from the Deepwater Horizon explosion and oil spill. A learning collaborative

[2] Information about the National Climate Assessment Sustained Assessment Program is available at https://www.globalchange.gov/engage/process-products/sustained-assessment#PublicComment.

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would also be a critical, seminal vehicle to advance the science, meaning, and utility of measuring resilience, as different parties and stakeholders engaged in resilience work together to ascertain the best ways to track progress.

Convening Participating GRP Community Resilience Initiative Communities

The first level of participation in the learning collaborative would include the communities that participate in the GRP community resilience initiative (see *Recommendation 5*). The GRP would convene the participating communities on a regular basis and allow for learning on multiple levels: communities will learn from each other and from external expertise brought by the GRP to the meetings, and the GRP will learn from the communities to amplify those findings to broader audiences. These regular convening events could also include other stakeholders that distribute resources, create policies, make investments, or have accountability for ensuring returns on those investments.

***Action*: The GRP should organize opportunities for information exchanges among the communities that participate in its community resilience initiative in order to facilitate collaborative learning, capacity building among stakeholders, and training and mentoring, including a focus on measures of resilience.**

Convening Other Gulf Region Stakeholders

The Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act (RESTORE Act)[3] of 2012 dedicates 80 percent of all administrative and civil penalties related to the Deepwater Horizon oil spill to the Gulf Coast Restoration Trust Fund and outlines a structure for the use of funds to restore and protect the natural resources, ecosystems, and economy of the Gulf coast region. As stipulated in the RESTORE Act, each Gulf region state (Alabama, Mississippi, Florida, Louisiana, and Texas) received equal amounts to establish centers of excellence to conduct research within topical areas—topical areas that overlap with the GRP's program initiatives. The centers of excellence and the GRP share a charge to spend settlement resources to research, study, or enhance ecosystem management; safe, healthy, and resilient communities; and offshore energy development. It is worth noting that none of these programs currently support human health research. Beyond the centers of excellence, there are number of other funding programs that were established from civil and criminal settlements of the Deepwater Horizon explosion and oil spill.[4] Some of these programs have already completed their program periods of performance (e.g., Gulf Region Health Outreach Program [Lichtveld, Covert, and

[3] For more information about the RESTORE Act visit https://www.restorethegulf.gov/sites/default/files/RESTORE%20ACT%20July2012.pdf.

[4] See https://dwhprojecttracker.org/about/about-the-funders.

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Sherman, 2017]; MOEX Supplemental Environmental Projects), while others have longer program timelines.

The GRP is in a particular position of strength to exercise the convening power of the National Academies in the Gulf region to bring these related funding programs together to inform, be informed by, or catalyze collaborative efforts around common, shared goals for the Gulf region. ***Action*: The GRP should confer with other recipients of settlement funds from the Deepwater Horizon explosion and oil spill and/or organizations active in community resilience about collaborative efforts on common program elements.**

The GRP can advance the development of a resilience framework throughout the Gulf region. Through a Gulf region resilience learning collaborative, the GRP would support communities in the Gulf region that embark on long-term programs around the development and measurement of resilience. At a minimum, the GRP should:

- Serve as a focal point among Deepwater Horizon funding programs, states, and communities of the Gulf region on resilience matters. The GRP could offer program and collaborative activities to work with states and communities in carrying out their resilience programs, and the GRP could gain and share information regarding what activities are being successfully pursued by similar communities in the region. The GRP could also lead the collection of research by annually synthesizing the disparate investments, activities, projects, and programs aimed at advancing resilience in the Gulf region.
- Continue to support research activities that respond to the needs of the Gulf region related to the GRP mission.
- Publish research findings and lessons learned.

LONGITUDINAL RESEARCH

***Recommendation 8.* The Gulf Research Program should implement longitudinal research associated with its community resilience program.**

Through longitudinal research, the GRP can bring together communities and research institutions across the Gulf region, as well as academic and governmental research facilities in the Gulf and beyond. A new approach to community resilience research should connect public participation with long-term assessments in communities over multiple years and multiple hazard events. While the communities would likely be located within the Gulf states, the types of research, (meta)analysis, and data integration could involve, in addition to local researchers already embedded in their Gulf state communities, experts and researchers from outside of the Gulf region.

Long-term, periodic, comprehensive resilience assessment remains an unmet need (NASEM, 2017b). Such assessment is hampered by the inability or untested

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ability of most resilience measures to account for longitudinal or dynamic changes in community resilience. By aiming to fill this void, a GRP longitudinal research program related to community resilience could realize at least two benefits: 1) a targeted examination of the dynamic state of communities influenced by changes in risk and resilience over time; and 2) the advantage of the GRP position to develop a research portfolio that can link information and data from disparate programs with one another and to community resilience priorities (Finding 4.1). Ultimately, the longitudinal research program should integrate research, data, and information with decision making. As a result, the GRP could offer guidance on the long-term impacts of community resilience in the Gulf region in the three decades following the Deepwater Horizon oil spill.

Long-term Community Resilience Assessments

Building community resilience occurs over timelines measured in years. A longitudinal research program on community resilience would provide benefits of other multidecadal studies, namely, to have the "power to transform understanding . . . in the face of uncertain future conditions" (NASEM, 2018). The Gulf region is affected by episodic natural disasters (hurricanes, coastal storms, inland flooding); technological accidents such as oil spills; and vexing public health threats, economic challenges, and institutional racism (Cosco et al., 2017; Cutter and Emrich, 2006; Cutter et al., 2006). Since 2005, the Gulf region has endured some of the country's costliest hurricanes: Dennis, Katrina, Rita, and Wilma (2005); Gustav and Ike (2008); Irene (2011); Isaac (2012); Hermine and Matthew (2016); and Harvey and Irma (2017), in addition to other weather-related events, such as the Baton Rouge floods of 2016 or the Tax Day Flood in Texas (2016), and the Deepwater Horizon oil spill itself in 2010. Cross-sectional or short-term research cannot capture the sequential nature of the impacts that these events have had on resilience efforts, nor the consequences of limited research investments. Only longitudinal, observational, experimental, and monitoring programs can examine the drivers of change and cascading impacts on a community over time (NASEM, 2018). Long-term research with a periodicity of minimally 5 or more years would be useful in the Gulf. In addition, researchers need the ability to test resilience measurement tools over the long term to refine and validate them for usability and usefulness.

Most resilience measures—such as infrastructure specification performance or adherence to building codes—provide a snapshot in time focused on short-term operational decisions (e.g., investments). Even in places that have implemented resilience measures, few measures have been applied more than once, applied over timelines commensurate with capturing dynamic states of resilience development, or updated to improve their usability or usefulness (Chapter 2). Therefore, the GRP should take a leadership role and provide a platform for communities in the Gulf region to develop measurement approaches that address the current lack of temporal sensitivity to monitor changes over time.

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***Action*: The GRP should identify, collect, and maintain data that can be used to effectively monitor the changes in regional and community resilience and assess why these changes are occurring.**

Integrating and Synthesizing Data for Community Resilience, Measures, and Decision Making

In addition to extended timelines, community resilience measurement and research need to include various disciplines to account for data, information, and assessments of community resilience. Several disciplines are key. For example, epidemiologic cohort studies can examine the impact of acute and chronic stressors impacting vulnerable communities; ecological and social science studies can make important contributions in determining how communities perceive and act on risks; and research involving the built environment can identify how infrastructure planning influences community resilience over time. Linking various data sources, information, and scientific methods to resilience priorities requires participation of data science experts to advance collective knowledge about factors influencing community resilience, including slow-moving stressors such as climate change, housing shortages, the persistent burden of health disparities, or the legacy effects of community historical trauma. A longitudinal community resilience research program would strengthen methods to conduct integrated analyses and data synthesis across different types of data and information to generate new metrics of resilience. Thus, effective community resilience measurement and research require investments in longitudinal designs, as well as incentives for transdisciplinary teams to collaborate in longitudinal, cross-sectoral investigations.

To improve the usefulness of resilience research, it must be closely aligned with action, investment, policy, and other decision making. Especially useful would be linking relevant information—especially from disparate or unexpected sources—to existing community efforts, budgets, and priorities (Finding 4.1). An integrated approach that engages various decision makers, researchers, and organizations could help facilitate broader community engagement, information exchange, and local application of resilience measures.

Comprehensive community resilience measurement needs longitudinal, transdisciplinary studies to account for periods before, during, after, and between shock events. Resilience investments target a range of dynamic stressors and short- and long-term gains, and those gains can be tracked along or across multiple sectors (Finding 4.2); long-term gains can only be assessed over commensurate times. A longitudinal approach is a promising way to build the infrastructure and the rigorous methodology to conduct such long-term assessments. Given the long timelines, the GRP should include new and innovative technologies in its longitudinal community resilience research program such as applications of artificial intelligence, crowd sourcing, and meta-analysis.

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***Action*: The GRP should proceed with investing, developing, and designing a longitudinal research program to collect, analyze, and integrate data from different sources that have relevance to community capitals, investments, priorities, and measures. Such integrated analysis should be relevant to existing budgets, policies, priorities, and investments.**

CONCLUSION

The need to build resilience across the Gulf region has never been more acute. Compared to other Gulf Coast organizations engaged in the aftermath of the 2010 Deepwater Horizon oil spill, the GRP is in a unique position to substantially advance community resilience. The GRP should consider taking four main actions to foster resilience and the science of resilience measurement to fulfill its mandate in accordance with the $500 million endowment from the Deepwater Horizon criminal settlements.

1. The GRP should develop a major initiative around building or enhancing community resilience in several communities across the Gulf region.
2. For each community in the GRP community resilience initiative, the GRP should employ a community resilience framework that includes: (1) community engagement, (2) resilience across multiple community capitals, (3) measures and ways to track progress that are useful to decision makers, and (4) investments in resilience that result in multiple benefits.
3. The GRP should create a resilience learning collaborative for stakeholders to exchange information, approaches, challenges, and successes in their respective and collective work to advance community resilience in the Gulf region. The collaborative participants should include government (local, state, federal levels), industry, academia, and other organizations engaged in addressing community resilience in the states of the Gulf of Mexico.
4. The GRP should implement longitudinal research associated with its community resilience initiative that includes systematic collection, analysis, translation, and dissemination of data of various sources over time periods with periodicities of 5 or more years.

These recommended actions will help the GRP serve the Gulf region through outreach activities, opportunities for collaborative learning, applied research, and timely data collection to identify, capture, and analyze the successes, limitations, and failures of resilience activities in the Gulf region. By including researchers, decision makers, and community stakeholders, and undergirded by the scientific imprimatur that is the signature of the National Academies, the GRP can use its platform of resources and a quarter-century of time to effect an enduring, sustained legacy of resilience in the Gulf of Mexico and beyond.

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Appendix A

Committee Member Biographies

COMMITTEE BIOGRAPHIES

Thad W. Allen, *co-chair,* is senior executive advisor in Booz Allen's Departments of Justice and Homeland Security business in the civil market, leading the development of thought leadership and client engagement regarding the future direction of law enforcement and homeland security. He is known for his expertise in bringing together government and nongovernment entities to address major challenges in a "whole of government" approach designed to achieve a unity of effort. Mr. Allen completed his distinguished career in the U.S. Coast Guard as its 23rd Commandant. In 2010, President Barack Obama selected Mr. Allen to serve as the national incident commander for the unified response to the Deepwater Horizon oil spill in the Gulf of Mexico. Working closely with the U.S. Environmental Protection Agency; the Department of Homeland Security; the Departments of Defense, Interior, Commerce, and Health and Human Services; state and local entities; and BP, he sought to bring a unity of effort to response operations. Prior to his assignment as commandant, Mr. Allen served as Coast Guard chief of staff. During his tenure in that position, in 2005 he was designated principal federal official for the U.S. government's response and recovery operations in the aftermath of Hurricanes Katrina and Rita throughout the Gulf Coast region. Other Coast Guard assignments included commander, Atlantic Area, where in 2001 he led the Coast Guard's Atlantic Area forces following the September 11 attacks. He previously served as commander, Seventh Coast Guard District, where he oversaw all operations in the southeastern United States and in the Caribbean. Prior to joining Booz Allen, Mr. Allen served with the RAND Corporation. He is a fellow in the National Academy of Public Administration and a member of

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the Council on Foreign Relations. He also currently serves as a director on the Coast Guard Foundation and Partnership for Public Service. New York Governor Andrew Cuomo appointed Mr. Allen to the New York State Respond Commission tasked with finding ways to ensure that New York State is ready to respond to future weather-related disasters. Mr. Allen is a 1971 graduate of the U.S. Coast Guard Academy. He holds a master's degree in public administration from the George Washington University from which he received the Alumni Achievement Award in 2006. He also holds an M.S. degree in management from the Sloan School of Management at the Massachusetts Institute of Technology. Mr. Allen has been awarded honorary doctorate degrees from George Mason University, the National Defense University, and the National Graduate School.

Gerald E. Galloway, Jr. (member, National Academy of Engineering), *co-chair*, is a Glenn L. Martin Institute Professor of Engineering, Department of Civil and Environmental Engineering, University of Maryland; a faculty fellow of the Texas A&M University Institute for Advanced Study; and a visiting professor at the Galveston campus. His 38-year career in the military included positions such as commander of the Army Corps of Engineers District in Vicksburg, MS; member of the Mississippi River Commission; and professor and founding head of the Department of Geography and Environmental Engineering and dean of the Academic Board at the U.S. Military Academy. A civil engineer, public administrator, and geographer, Dr. Galloway's current research focuses on the development of U.S. national water policy and disaster resilience in general and national floodplain management policy and the potential impacts of climate change on national security in particular. He currently serves as a consultant to several federal, state, and nongovernmental agencies on water resources policy development and flood risk management including the Louisiana Governor's Advisory Commission on Coastal Protection, Restoration, and Conservation; the Maryland Coast Smart Council; an international panel of experts examining the flooding threats to Florence, Italy; and a panel of experts advising on sea level rise challenges in Singapore. Prior to joining the University of Maryland, Dr. Galloway was vice president of geospatial strategies for the ES3 sector of the Titan Corporation. He was a 6-year member of the National Research Council's Water Science and Technology Board and has served as chair or member of 13 National Research Council committees. He is a member of the National Academy of Engineering, the National Academy of Public Administration, and the National Academy of Construction. After he retired from the Army in 1995 as a brigadier general, Dr. Galloway earned his M.S.E. at Princeton, his M.P.A. at Penn State (Capitol campus), and his Ph.D. in geography (specializing in water resources) from the University of North Carolina at Chapel Hill.

Michael W. Beck is the lead marine scientist for The Nature Conservancy and an adjunct professor in ocean sciences at the University of California Santa Cruz,

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where he is based. Dr. Beck works on coastal marine conservation in five continents across science, business, and policy to bring clear tools and results to decision makers. He focuses on building coastal resilience in the interface between adaptation and conservation, working to reduce risks to people, property, and nature. Dr. Beck has authored more than 60 peer-reviewed science articles. His work covers topics from the role of coral reefs in reducing risks from storms to the effects of people on extinctions of Pleistocene mammals. He was a Fulbright fellow and an Australian Research Council postdoctoral fellow at the University of Sydney. He has served on advisory boards and panels for the National Oceanic and Atmospheric Administration, the Environmental Protection Agency, and the National Academy of Sciences. In 2012, Dr. Beck was selected as a Pew marine conservation fellow. His main areas of work include coastal hazards mitigation and climate adaptation in the United States, Caribbean, and Micronesia; habitat restoration and oyster reefs at risk; marine spatial planning in the United States and internationally; restoration investments following the Deepwater Horizon oil spill; and the nursery role of near-shore habitats such as kelp forests and on marine conservation agreements, including the lease and ownership of submerged lands. Dr. Beck has an M.S. in environmental sciences from the University of Virginia and a Ph.D. in biological sciences from Florida State University.

Anita Chandra is vice president and director of social and economic well-being and senior policy researcher at the RAND Corporation. Prior to her position as director of justice, infrastructure, and environment, she served as director of RAND's Behavioral and Policy Sciences Department. She also leads studies on civic wellbeing and urban planning; community resilience and long-term disaster recovery; effects of military deployment; health in all policies; and child health and development. Throughout her career, Dr. Chandra has engaged government and nongovernmental partners to consider cross-sector solutions for improving community well-being and to build more robust systems and evaluation capacity. This work has taken many forms, including engaging with federal and local government agencies on building systems for emergency preparedness and resilience both in the United States and globally; partnering with private sector organizations to develop the science base around child systems; and collaborating with city governments and foundations to reform data systems and measure sustainability, well-being, and civic transformation. Dr. Chandra has also partnered with community organizations to conduct broad-scale health and environmental needs assessments, to examine the integration of health and human service systems, and to determine how to address the needs of historically vulnerable populations in human service systems. These projects have occurred in partnership with businesses, foundations, and other community organizations. Dr. Chandra earned a Dr.P.H. from the Johns Hopkins Bloomberg School of Public Health.

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Erin D. Coryell joined the Margaret A. Cargill Foundation in 2010 as program officer. She is responsible for the development, strategic direction, and grant making of the foundation's domestic disaster program, which is focused on the Midwest. Ms. Coryell manages a portfolio of grants that span the continuum of disaster preparedness through long-term recovery projects in a 10-state region. Her background spans historic preservation, nonprofits, urban development, and social and cultural issues regarding land use. Prior to joining the foundation, Ms. Coryell worked in field operations for the Federal Emergency Management Agency's Emergency Support Function #14 Long-Term Community Recovery program and was deployed for disaster declarations in Iowa, Kansas, Missouri, and Nebraska. She also was previously the director of the Philadelphia Regional Fund, a grant program for community-serving historic houses of worship for a national nonprofit supported by foundation and government funding. She has run her own preservation consulting business; authored a successful New Market Tax Credit application for a faith-based organization in south central Los Angeles; worked for a construction company on one of Seattle's first Hope VI mixed-income housing projects to use sustainable building practices; and worked for an urban developer on the restoration of a landmarked Nordstrom's department store. Ms. Coryell graduated from Bard College with a B.A. in art history and from Cornell University's City and Regional Planning Program with an M.A. in historic preservation planning.

Susan L. Cutter is a Carolina distinguished professor of geography at the University of South Carolina, where she directs the Hazards and Vulnerability Research Institute. Her primary research interests are in the area of disaster vulnerability/resilience science—what makes people and the places where they live vulnerable to extreme events, and how vulnerability and resilience are measured, monitored, and assessed. She has authored or edited 13 books and more than 150 peer-reviewed articles and book chapters. Dr. Cutter has led post-disaster field studies of the role of geographic information technologies in rescue and relief operations (in the September 11 World Trade Center attack) and studies of evacuation behavior from Three Mile Island (1979), Hurricane Floyd (1999), and the Graniteville, SC, train derailment and chlorine spill (2005). In 2006 she led a Hurricane Katrina post-event field team and ensuing 5-year study to examine the long-term recovery along the Mississippi Coast. In 2012, she led a Hurricane Sandy recovery team to examine the differential recovery along New Jersey's coast. Dr. Cutter has provided expert testimony to Congress on hazards and vulnerability, was a member of the U.S. Army Corps of Engineers Interagency Performance Evaluation Task Force evaluating the social impacts of the New Orleans and Southeast Louisiana Hurricane Protection System in response to Hurricane Katrina, and was a juror for the Rebuild by Design competition for Hurricane Sandy reconstruction. Her policy-relevant work focuses on emergency management and disaster recovery

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at local, state, national, and international levels, with funding from the National Science Foundation, the U.S. Army Corps of Engineers, National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, U.S. Geological Survey, Federal Emergency Management Agency, Department of Homeland Security, South Carolina's Emergency Management Division and State Law Enforcement Division, and Florida's Department of Health. Dr. Cutter serves on many national advisory boards and committees including those of National Research Council, the American Association for the Advancement of Science, the National Science Foundation, the Natural Hazards Center, and the National Institute of Standards and Technology. She also served as vice-chair of the Integrated Research on Disaster Risk Science Committee supported by the International Social Science Council, International Council for Science (ICSU), and the United Nations Office for Disaster Risk Reduction. Dr. Cutter serves as co-executive editor of *Environment*; associate editor of *Weather, Climate, and Society*; and on the advisory board of the *Journal of Extreme Events*. She also is serving as the editor in chief for the Oxford Research Encyclopedia of Natural Hazard Science. Dr. Cutter received her B.A. from California State University, East Bay, and her M.A. and Ph.D. (1976) from the University of Chicago.

Ann-Margaret Esnard is a distinguished university professor in the Department of Public Management and Policy at Georgia State University. She was hired in 2013 as part of the cluster on "Shaping the Future of Cities" during the third phase of the university's Second Century Initiative. She served as the chair of Georgia State University's Council for the Progress of Cities from 2014 to 2016. Her expertise encompasses urban planning, disaster planning, vulnerability assessment, and geographic information system (GIS)/spatial analysis. Dr. Esnard has been involved in a number of research initiatives including National Science Foundation–funded projects on topics of population displacement from catastrophic disasters, school recovery after disasters, long-term recovery, and community resilience. She is the coauthor of the book *Displaced by Disasters: Recovery and Resilience in a Globalizing World* (2014) and co-editor of the book *Coming Home after Disaster: Multiple Dimensions of Housing Recovery* (2017). She has served on a number of state and national committees including the Disasters Roundtable of the National Academy of Sciences, the National Research Council's Committee on Private-Public Sector Collaboration to Enhance Community Disaster Resilience, and the State of Florida Post-Disaster Redevelopment Planning Initiative. Dr. Esnard holds degrees in agricultural engineering (B.Sc., University of the West Indies-Trinidad), agronomy and soils (M.S., University of Puerto Rico-Mayaguez), and regional planning (Ph.D., University of Massachusetts Amherst), and she completed a 2-year post-doc at the University of North Carolina at Chapel Hill.

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Howard Frumkin is head of Our Planet, Our Health at Wellcome Trust. Prior to this he was professor of environmental and occupational health sciences at the University of Washington School of Public Health, where he served as dean from 2010 through 2016. Dr. Frumkin is an internist, environmental and occupational medicine specialist, and epidemiologist, who has worked in academia and public service. From 2005 to 2010, he held leadership roles at the Centers for Disease Control and Prevention; first, he was director of the National Center for Environmental Health and Agency for Toxic Substances and Disease Registry, where he created programs in climate change and in healthy community design; launched training programs for college students, doctoral students, and postdocs; expanded its Biomonitoring and Environmental Public Health Tracking programs; and launched its National Conversation on Public Health and Chemical Exposures. Subsequently, he was special assistant to the Centers for Disease Control and Prevention director for climate change and health. From 1990 to 2005, he was professor and chair of environmental and occupational health at Emory University's Rollins School of Public Health and professor of medicine at Emory Medical School. Dr. Frumkin serves on the boards of the Seattle Parks Foundation, the Bullitt Foundation, the Children and Nature Network, and the Washington Global Health Alliance; as chair of the Wellcome Trust "Our Planet, Our Health" funding committee; and on advisory boards for the Partnership for Active Transportation, the Planetary Health Alliance, and the Center for Design and Health at the University of Virginia School of Architecture. He previously served on the national boards of directors of the U.S. Green Building Council and of Physicians for Social Responsibility, as president of the Association of Occupational and Environmental Clinics, as chair of the science board of the American Public Health Association, on the American Institute of Architects Design and Health Leadership Group, on the National Toxicology Program Board of Scientific Counselors, on the board of the National Environmental Education Foundation, on the National Research Council Committee on Sustainability Linkages in the Federal Government, as part of the Washington Department of Ecology Toxics Reduction Strategy Group, on the board of the Pacific Northwest Diabetes Research Institute, and on Seattle's Green Ribbon Commission. As a member of the Environmental Protection Agency's Children's Health Protection Advisory Committee, Dr. Frumkin chaired the Smart Growth and Climate Change work groups. A graduate of the Institute for Georgia Environmental Leadership, he was named Environmental Professional of the Year by the Georgia Environmental Council in 2004. His research interests include public health aspects of the built environment, climate change, energy policy, and nature contact; toxic effects of chemicals; and environmental health policy. He is the author or co-author of more than 200 scientific journal articles and chapters and several books, including the standard environmental health textbook *Environmental Health: From Global to Local*. He is board-certified in internal medicine and in environmental and occupational medicine, and is a fellow of the American College of Physicians,

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the American College of Occupational and Environmental Medicine, Collegium Ramazzini, and the Royal College of Physicians of Ireland. Dr. Frumkin received his A.B. from Brown University, his M.D. from the University of Pennsylvania, his M.P.H. and Dr.P.H. from Harvard University, his internal medicine training at the Hospital of the University of Pennsylvania and Cambridge Hospital, and his environmental and occupational medicine training at Harvard University.

Melanie Gall is a faculty member of Arizona State University's Emergency Management and Homeland Security program and the School of Community Resources and Development. Prior to joining Arizona State University, she worked as a researcher at the Hazards and Vulnerability Research Institute at the University of South Carolina as well as in the Disaster Science and Management Program at Louisiana State University. Dr. Gall's research combines a mixed-method approach to explore the impacts of extreme events on society. Her expertise lies in risk metrics (e.g., disaster losses, vulnerability indexes), hazard mitigation, and climate change adaptation planning, as well as environmental modeling. The applied nature of Dr. Gall's work allows her to work closely with emergency management agencies and nonprofit organizations. She has conducted post-disaster field work in Mozambique, Haiti, New Jersey, Louisiana, Mississippi, and South Carolina. She has published in journals including *Natural Hazards Review*, *Bulletin of the American Meteorological Society*, and *Nature Climate Change*. She is a certified floodplain manager and received her geography degrees from the University of South Carolina (Ph.D.), University of Salzburg in Austria (M.S.), and University of Heidelberg (B.S.).

Maureen Lichtveld (member, National Academy of Medicine) has 35 years of experience in environmental public health and is professor and chair of the Department of Global Environmental Health Sciences, School of Public Health and Tropical Medicine, Tulane University. Beginning in 1987, she served as one of the highest ranking environmental health scientists with the Centers for Disease Control and Prevention's Agency for Toxic Substances and Disease Registry designing research tools and protocols to guide national environmental health studies in communities located near hazardous waste sites, as well as science-driven policies, often accompanied by congressional testimonies. Her research focuses on environmentally induced disease including asthma and cancer, health disparities, environmental health policy, disaster preparedness, and public health systems. She holds an endowed chair in environmental policy and is associate director of population sciences at the Louisiana Cancer Research Consortium. Dr. Lichtveld has a track record in community-based participatory research with a special emphasis on persistent environmental health threats affecting health disparate communities living in disaster-prone areas. Her $29 million research portfolio encompasses both national and global environmental health research. As director of the Center for Gulf Coast Environmental Health Research, Leadership,

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and Strategic Initiatives, Dr. Lichtveld serves as the principal investigator of several Gulf Coast–associated environmental health research and capacity-building projects ascertaining the potential impact of the Gulf of Mexico oil spill. She was awarded the Caribbean Consortium for Research in Environmental and Occupational Health, a National Institutes of Health-Fogarty International Center research grant with the research center at the Academic Hospital in Suriname and the University of Suriname, a first-time National Institutes of Health award in that Caribbean country. Since 1988, she has served as a consultant to the National Academy of Medicine (formerly the Institute of Medicine) on complex research issues ranging from environmental health and technological disasters to public health systems research and cancer policy. Of special note is her contribution as environmental health expert in the aftermath of Hurricane Katrina and the Gulf of Mexico oil spill. Dr. Lichtveld is a member of the National Advisory Environmental Health Sciences Council of the National Institutes of Health's National Institute of Environmental Health Sciences; the Environmental Protection Agency's Scientific Advisory Board; the National Academy of Sciences-Institute of Medicine Roundtable on Environmental Health Sciences, Research, and Medicine; and a member of the Health Disparities Subcommittee of the Advisory Committee to the director of the Centers for Disease Control and Prevention. She was elected as chair of the editorial board of the *American Journal of Public Health* and serves as the current president of the Hispanic-Serving Health Professions Schools. Dr. Lichtveld was honored as Centers for Disease Control and Prevention's Environmental Health Scientist of the Year and twice named Woman of the Year by the City of New Orleans. She earned her M.D. at the University of Suriname in 1981 and M.P.H. in environmental health sciences at Johns Hopkins University School of Hygiene and Public Health in 1986.

Carlos Martín is a senior fellow in the Metropolitan Housing and Communities Policy Center at the Urban Institute where he leads research and evaluations of the physical qualities of housing and communities and the industry that builds them. Dr. Martín, trained as an architect and construction engineer, uses his technical training to connect the nuts and bolts of housing—technology, design, workers, and materials—to its social outcomes for residents and the cities in which they live. His areas of expertise include green housing policies, disaster mitigation, low-income housing quality, the construction workforce, and development regulations. He has experience with descriptive analysis; qualitative implementation studies; evaluation technical assistance; and experimental evaluations for public, nonprofit, and philanthropic clients in the United States and abroad. Recent work includes evaluations of the Department of Housing and Urban Development's Rebuild by Design formation following Hurricane Sandy; the National Disaster Resilience Competition's Resilience Academies; home rebuilding rates with Community Development Block Grants for Disaster Recovery; and the Rockefeller Foundation's 100 Resilient Cities. Publications

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from his past research projects include *Housing Recovery on the Gulf Coast, Phase II* (https://www.huduser.gov/publications/pdf/gulfcoast_phase2.pdf) and *The State of the Residential Construction Industry* (https://bipartisanpolicy.org/wp-content/uploads/sites/default/files/State%20of%20the%20Residential%20Construction%20Industry_Formatted_8-31.pdf). Before joining the Urban Institute, Dr. Martín was assistant staff vice president at the National Association of Home Builders for Construction Codes and Standards, SRP Professor for Energy and the Environment at Arizona State University's Del E. Webb School of Construction and School of Architecture, and coordinator for the Department of Housing and Urban Development's Partnership for Advancing Technology in Housing. He received his B.S.A.D. in architecture from the Massachusetts Institute of Technology and his M.S. and Ph.D. in civil and environmental engineering from Stanford University.

Chris Poland (member, National Academy of Engineering) is an internationally recognized authority on earthquake engineering and champion of disaster resilience. His passion for vibrant, sustainable, and healthy communities drives his consulting practice. He focuses on community resilience and the buildings and systems that contribute to it. Mr. Poland is currently a community resilience fellow at the National Institute of Standards and Technology and member of the institute's Community Resilience Panel. He is the past chair of the advisory committee to the National Earthquake Hazards Reduction Program, and current chairman of the Advisory Committee on Structural Safety of Department of Veterans Affairs Facilities. As chair of the 100th Anniversary Earthquake Conference in San Francisco in April 2006, he shared the stage with California Governor Arnold Schwarzenegger and Senator Dianne Feinstein in an internationally covered event that brought the nation to think proactively about earthquake danger. Mr. Poland served as the chair of the American Society of Civil Engineers (ASCE) Seismic Rehabilitation of Existing Buildings Standards Committee completing both ASCE 31 and ASCE 41, standards for the evaluation and rehabilitation of existing buildings that are used worldwide. He served on the board of directors for the San Francisco Bay Area Planning and Urban Research Association, co-chaired its Resilient City Initiative, and led the publication of *The Disaster Resilient City*. Mr. Poland serves on the board of the ASCE Structural Engineering Institute, has a leadership position in the ASCE Infrastructure Resilience Division, and is a member of the board of the US Resiliency Council. He served on the board for the San Francisco Chamber of Commerce and was the co-chair of the San Francisco Lifelines Council with City Administrator Naomi Kelly. Mr. Poland was inducted into the National Academy of Engineering in 2009. He received the Earthquake Engineering Research Institute's Alquist Award in 2006 and the Housner Medal in 2017. He is a fellow of the American Council of Engineering Companies and the ASCE Structural Engineering Institute, and an honorary member of the Earthquake Engineering Research Institute and the Structural Engineers Association of

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California. His structural engineering career spans 40+ years and includes new design work, seismic analysis and strengthening of existing buildings, structural failure analysis, and historic preservation. Until his retirement, he was a senior principal, chairman, and CEO of Degenkolb Engineers during his 40 years with the firm from 1974 through 2014. Mr. Poland received his M.S. in structural engineering from Stanford University.

Liesel Ritchie is associate director of the Center for the Study of Disasters and Extreme Events at Oklahoma State University and an associate professor in the Department of Sociology. During her career, Dr. Ritchie has studied a range of disaster events, including the Exxon Valdez and BP Deepwater Horizon oil spills, the Tennessee Valley Authority coal ash release, Hurricane Katrina, and earthquakes in Haiti and New Zealand. Since 2000, her focus has been on the social impacts of disasters and community resilience, with an emphasis on technological disasters, social capital, and renewable resource communities, topics on which she has published widely. Dr. Ritchie has more than 20 years of experience in evaluation and research. Prior to joining Oklahoma State University, she served for 10 years as associate director of the Natural Hazards Center at the University of Colorado Boulder and a research professor with joint appointments in the university's Institute of Behavioral Science and Environmental Studies Program. Dr. Ritchie was a senior research associate at the Evaluation Center at Western Michigan University and served for 6 years as coordinator for the Social Science Research Center's Evaluation and Decision Support Laboratory at Mississippi State University. Dr. Ritchie has been the principal investigator or co-principal investigator on more than 80 projects and authored or coauthored more than 70 technical reports working with agencies including the National Aeronautics and Space Administration, National Science Foundation, U.S. Geological Survey, Federal Emergency Management Agency, U.S. Department of Agriculture, National Oceanic and Atmospheric Administration, and Department of the Interior. She is a National Institute of Standards and Technology disaster resilience fellow and serves on two National Academies Advisory Boards—one for the Gulf Research Program and another for the Koshland Public Engagement Program.

Kathryn Sullivan (member, National Academy of Engineering) is a senior fellow at the Potomac Institute for Policy Studies and ambassador at large at the Smithsonian National Air and Space Museum. She was the Smithsonian's Lindbergh fellow in aerospace history from March to August 2017. Prior to this, she served from 2013 to 2017 as the under secretary of commerce for oceans and atmosphere and National Oceanic and Atmospheric Administration (NOAA) administrator. She is a distinguished scientist, renowned astronaut, and intrepid explorer. Prior to her service as under secretary and NOAA administrator, Dr. Sullivan was assistant secretary of commerce for environmental observation and prediction and deputy administrator, and also performed the duties of NOAA's chief scientist,

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a vacant position. As assistant secretary, Dr. Sullivan played a central role in directing administration and NOAA priority work in the areas of weather and water services, climate science and services, integrated mapping services, and Earth-observing capabilities. She also provided agency-wide direction with regard to satellites, space weather, water, and ocean observations and forecasts to best serve American communities and businesses. As deputy administrator, she oversaw the smooth operation of the agency. Dr. Sullivan is the U.S. co-chair of the Group on Earth Observations, an intergovernmental body that is building a global Earth observation system of systems to provide environmental intelligence relevant to societal needs. Dr. Sullivan's expertise spans the frontiers of space and sea. An accomplished oceanographer, she was appointed NOAA's chief scientist in 1993, where she oversaw a research and technology portfolio that included fisheries biology, climate change, satellite instrumentation, and marine biodiversity. She was the inaugural director of the Battelle Center for Mathematics and Science Education Policy in the John Glenn School of Public Affairs at Ohio State University. Prior to joining Ohio State, she served a decade as president and CEO of the Center of Science and Industry in Columbus, Ohio, one of the nation's leading science museums. Dr. Sullivan joined the center after 3 years of service as chief scientist. She was one of the first six women selected to join the National Aeronautics and Space Administration astronaut corps in 1978 and holds the distinction of being the first American woman to walk in space. She flew on three shuttle missions during her 15-year tenure, including the mission that deployed the Hubble Space Telescope. In February 2016, Dr. Sullivan was elected a member of the National Academy of Engineering. She was also named a fellow of the American Meteorological Society, the nation's premier scientific and professional organization promoting and disseminating information about the atmospheric, oceanic, and hydrologic services. Dr. Sullivan has also served on the National Science Board (2004-2010) and as an oceanographer in the U.S. Navy Reserve (1988-2006). She holds a bachelor's degree in earth sciences from the University of California at Santa Cruz and a doctorate in geology from Dalhousie University in Canada.

STAFF BIOGRAPHIES

Lauren Alexander Augustine is the director of Policy and Global Affairs's Program on Risk, Resilience, and Extreme Events at the National Academies of Sciences, Engineering, and Medicine. The marquis program is the Resilient America Roundtable, a set of activities that uses science, analysis, and technology in combination with community engagement to build resilience to disasters and other disruptions in four U.S. communities: Cedar Rapids, IA; Charleston, SC; Seattle, WA; and Tulsa, OK. From 2010-2015, she served on the World Economic Forum's Global Agenda Council on Risk and Resilience; was a member of the advisory board for the American Geophysical Union's Thriving Earth Exchange

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program; and was a juror on the Rebuild by Design resilience competition for recovery after Hurricane Sandy. She was also a juror for Rebuild by Design in San Francisco (2017). She currently assists with the United Nations International Strategy for Disaster Reduction (UNISDR) Business and Science Forum. Dr. Augustine joined the Academies in 2002. In her tenure at the Academies, she was a study director for water science policy issues on the Water Science and Technology Board (2002 to 2008) and the deputy director for the African Science Academy Development Initiative, a decadal, cross-academies program that built scientific capacity in national academies of science in eight African countries (2007 to 2013). From 2008 to 2013, she directed the Disasters Roundtable at the Academy. Her most recent positions at the Academy entail her developing a portfolio on natural disasters and ways that science can inform policy to reduce the risk and elevate society's resilience to them. Dr. Augustine earned her B.S. in applied mathematics and systems engineering and her master's degree in environmental planning and policy from the University of Virginia; she completed her Ph.D. in an interdisciplinary program that combined physical hydrology, geomorphology, and ecology at Harvard University.

Charlene Milliken is a senior program officer in Policy and Global Affairs's Resilient America Program at the National Academies of Sciences, Engineering, and Medicine where she manages programs and projects focused on building community resilience to disasters; flood risk, resilience, preparedness, and mitigation; and community resilience measurement. Before joining the National Academies in 2015, she worked for 7 years in the Department of Homeland Security's Science and Technology Directorate, where she was involved in programs and activities related to community resilience, terrorism, improvised explosive devices, technology transition, risk communication, and social media use during disasters. She supported management of the Science and Technology Directorate's Centers of Excellence Program and conducted research and participated in interagency efforts focused on national and homeland security issues. Dr. Milliken was a National Defense and Global Security S&T fellow through the American Association for the Advancement of Science from 2007 to 2009 and a Department of Homeland Security Research Fellow from 2009 to 2012. She received her B.A. in international relations from the University of Southern California and earned her Ph.D. in anthropology from the University of Pittsburgh. She conducted her dissertation research in Peru, where she investigated mortuary rituals and ancestor veneration of the ancient Wari civilization.

Jamie Biglow was a research assistant for the National Academies of Sciences, Engineering, and Medicine's Resilient America Program. Prior to joining the National Academies in early 2014, Ms. Biglow spent 3 years in the field of international development, including roles in program management, project development, and fund-raising. She has an M.A. in international affairs from the George

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Washington University concentrating in security studies. Ms. Biglow completed her B.A. at the State University of New York at New Paltz, with a double major in history and art history.

Maggie Esch was a research associate for the National Academies of Sciences, Engineering, and Medicine's Resilient America Program. Before joining the staff full-time, she was a Christine Mirzayan Science and Technology fellow from January to April 2017 working with the Resilient America Program. She received her B.S. in biology and B.A. in environmental studies from the University of Pittsburgh, and her M.S. in marine and estuary science from Western Washington University in Bellingham, WA. She completed her Ph.D. in environmental science and ecology at the University of North Carolina at Chapel Hill, with a focus on hydrological processes and groundwater input in a tidal salt marsh along the Gulf coast of Florida.

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Appendix B

Public Session Agendas

FIRST COMMITTEE MEETING

March 1, 2017
The National Academies of Sciences, Engineering, and Medicine
500 Fifth Street, NW
Conference Room 101
Washington, DC

11:30 am – 12:15 pm	**Meeting with the Study Sponsor**
1:15 – 3:00 pm	**Panel – How are other resilience programs measuring resilience?** • Mr. Steve Cauffman, Research Engineer, Community Resilience Program, National Institute of Standards and Technology • Ms. Sandy Eslinger, Senior Research and Policy Analyst, Office for Coastal Management, National Oceanic and Atmospheric Administration • Dr. Carlos Martin, Senior Fellow, Metropolitan Housing and Communities Policy Center, Urban Institute

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COMMUNITY MEETINGS – GULF COAST

June 20-21, 2017
Community Site Visits
Louisiana and Mississippi

June 20, 2017 Baton Rouge	
8:45 – 10:00 am	**Meeting with representatives from city government** • Mayor-President's Office • Center for Planning Excellence • Baton Rouge Community Development
10:30 – 11:30 am	**Meeting with state officials** • Louisiana Department of Health • Office of Homeland Security and Emergency Preparedness • Office of the Governor, Coastal Protection & Restoration Authority • Department of Transportation and Development
12:30 – 2:00 pm	**Meeting with community development representatives** • Office of Community Development • Office of the Secretary, LA Economic Development **Meeting with NGOs and Academia** • Foundation for LA • Baton Rouge Area Foundation • Greater Baton Rouge Food Bank • LSU AgCenter • LSU, Department of Geography and Anthropology

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2:30 – 4:00 pm	**Meeting with environmental organizations** • The Water Institute of the Gulf • Coalition to Restore Coastal Louisiana • LSU, Coastal Sustainability Studio • Louisiana Sea Grant **Meeting with representatives from the private sector** • Committee of 100 for Economic Development, Inc. • Baton Rouge Area Chamber • Central Chamber of Commerce • Louisiana Business Emergency Operations Center • Port of Delcambre
June 20, 2017 **New Orleans**	
8:00 – 9:00 am	**Meeting with representatives from the Port of New Orleans**
1:30 – 3:00 pm	**Meeting with government representatives** • Special Projects • Place-Based Planning • Resilience • Public Works • Housing Authority • Community Development • Homeland Security & Emergency Preparedness • City Planning Commission
3:30 – 5:00 pm	**Meeting with NGOs** • United Way • Boys and Girls Club of Southeast Louisiana • Center for Hazards Assessment, University of New Orleans • Evacuteer • The Salvation Army • The Deep South Center for Environmental Justice, Dillard University

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June 20, 2017 New Orleans	
9:00 – 10:30 am	**Meeting with representatives from the City of New Orleans** • New Orleans Health Department • Office of Homeland Security & Emergency Preparedness
11:00 am – 1:00 pm	**Meeting with Community Leaders** • United Houma Nation • Boat People SOS-Biloxi-Bayou La Batre • Mary Queen of Vietnam, Community Development Corporation • Franklin Avenue Baptist Church
1:15 – 3:15 pm	**Meeting with public health representatives** • Louisiana Department of Health • Louisiana Public Health Institute
3:15 – 4:15 pm	**Meeting with NGOs** • Greater New Orleans, Inc. • Lake Pontchartrain Basin Foundation

June 20, 2017 Mississippi	
9:00 – 10:30 am	**Meeting with community stakeholders in Waveland** • Public Works • Waveland Fire Department • Waveland Police • Mayor's Office
1:00 – 2:30 pm	**Meeting with government representatives in Gulfport** • Gulfport Fire Department • Mississippi Department of Marine Resources

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3:00 – 5:00 pm	**Meeting with NGOs in Gulfport** • United Way of Southern Mississippi • The Back Bay Mission • Gulf Coast Community Design Center • East Biloxi Community Collaborative • Steps Coalition (STEPS) • MS-AL Sea Grant Consortium • Mercy Housing and Human Development • MS Gulf Coast Community Foundation • Gulf Regional Planning Commission
June 21, 2017	
8:40 – 10:15 am	**Panel Session: Measuring Resilience in Institutions of Higher Education** • Tulane University • Dillard University • Loyola University • Xavier University

COMMUNITY MEETINGS – NEW YORK

August 8-10, 2017
Community Site Visits
New York, NY

August 8, 2017	
10:30 am – 12:30 pm	**Meeting with 100 Resilient Cities and Rockefeller Foundation**
2:30 – 5:00 pm	**Meeting with banking, financing, and reinsurance sectors** • Barclays • Citi • Goldman Sachs • Risk Management Solutions • SwissRe • XL Catlin • Zurich

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August 9, 2017

9:00 – 11:00 am Meeting with City of New York

- Office of Recovery and Resiliency
- Office of Emergency Management
- Department of Housing Preservation and Development
- Office of Management and Budget
- Department of City Planning
- Department of Environmental Protection
- New York City Panel on Climate Change

1:30 – 4:30 pm Meeting with Academia

- New York University
- Columbia University
- WE ACT

August 10, 2017

8:00 – 10:00 am Meeting with representatives from state government and transportation agencies

- State of New York
- Port Authority of New York & New Jersey
- New York Metropolitan Transportation Authority
- Baird Engineering

VIDEO CONFERENCE – NORTH DAKOTA

October 3, 2017
Video conference
Minot, North Dakota

4:00 – 5:30 pm Video conference with representatives from the Mayor's Office

VIDEO CONFERENCE – UNITED NATIONS OFFICE FOR DISASTER RISK REDUCTION

October 16, 2017

8:00 – 9:30 am Video conference with representatives from the United Nations Office for Disaster Risk Reduction

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VIDEO CONFERENCE – UNITED NATIONS DEVELOPMENT PROGRAMME

October 19, 2017

11:00 am – 12:30 pm	**Video conference with representatives from the United Nations Development Programme**

COMMUNITY MEETINGS – SOUTH DAKOTA

November 1-3, 2017
Community Site Visits
Rapid City and Pine Ridge Reservation, South Dakota

November 1, 2017 Rapid City	
2:30 – 4:00 pm	**Meeting with NGO and government representatives** • Center for Disaster Philanthropy • City of Rapid City • Lutheran Social Services of South Dakota • Partnership With Native Americans • South Dakota Office of Emergency Management • South Dakota State University Extension • NOAA

November 2, 2017 Pine Ridge Reservation	
10:00 am – 12:00 pm	**Meeting with Pine Ridge Long-term Recovery Committee (PRLTRC) and Community Representatives**
1:00 – 3:00 pm	**Meeting with Pine Ridge Emergency Management**

November 3, 2017 Rapid City	
9:00 – 10:30 am	**Meeting with NGOs** • American Red Cross Black Hills Office • Black Hills Knowledge Network • Rosebud Sioux Tribe • United Way of the Black Hills

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Appendix C

Measurement Tools Reviewed

1. **Alliance for National and Community Resilience Benchmarking System** (http://www.resilientalliance.org). The alliance is coordinated by the International Code Council and was embarking in 2018 on a resilience benchmarking effort for buildings, water, and energy with the intention of creating a "standard, usable, and easily understandable metric" for communities. No benchmark tools have been developed by the alliance to date otherwise.
2. **Baseline Resilience Indicators for Communities (BRIC)** (http://artsandsciences.sc.edu/geog/hvri/baseline-resilience-indicators-communities-bric). First published by Cutter, Burton, and Emrich (2010), Baseline Resilience Indicators for Communities is a quantitative index of pre-disaster community resilience at the county level designed to compare counties across the United States. Community dimensions included are social and economic capital, ecosystems, infrastructure, and institutional capacity, which are grouped into six indicators at the county level. The first version of the tool covered 49 indicators, culled down from an original 61. BRIC was integrated into a pilot National Risk Index tool by the Federal Emergency Management Agency in 2017 along with three other related measurement frameworks.
3. **Characteristics of a Disaster Resilient Community** (http://discovery.ucl.ac.uk/1346086/1/1346086.pdf). Twigg (2007) published a preliminary set of resilience characteristics with funding from a variety of British-based philanthropic and developmental aid agencies. The characteristics are organized around five different thematic areas, structured by function (governance, risk assessment, risk management, etc.). It has not been implemented as an analytic or measurement tool to date. The updated version (Twigg, 2009)

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adds more practical guidance on methods and applying the resource, based on feedback from field testing.

4. **City Resilience Index (CRI, also referred to as the City Resilience Framework or CRF)** (https://www.rockefellerfoundation.org/report/city-resilience-index). Produced by Arup in 2014, with support from the-Rockefeller Foundation, the CRI is based on intensive site visits and consultation with resilience literature. The preliminary sets of 52 indicators are categorized into four domains, each with as many as 127 data measures (or sub-indicators). The index is being piloted in several cities as of early 2019.
5. **Climate Resilience Screening Index (CRSI)** (https://edg.epa.gov/metadata/catalog/search/resource/details.page?uuid=https://doi.org/10.23719/1393586 and https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100SSN6.txt). Produced by the Environmental Protection Agency, the methodology for the CRSI was published in 2017 (Summers et al., 2017). The index is a composite measure composed of five domains (risk, governance, society, built environment, and natural environment), represented by 20 indicators, and calculated from 117 metrics. Scores are calculated at the county level and have been applied only once, with no revision for reliability or validity testing.
6. **Climate Risk and Adaptation Framework and Taxonomy (CRAFT)** (http://www.c40.org/programmes/climate-risk-adaptation-framework-and-taxonomy). Under guidance from the Bloomberg Philanthropies and C40, Arup developed a taxonomy of climate change–related hazard risks beginning in 2015 with the expectation of developing a reporting standard for participating C40 cities on adaptation actions and climate risk experiences. This includes a benchmarking process, which primarily serves as a checklist for administrative actions or plans. This reporting standard has not been released publicly as of early 2019.
7. **Coastal Resilience Decision Support System** (http://coastalresilience.org). The Nature Conservancy's coastal resilience program is an approach and a series of geospatial mapping tools that depict a variety of indicators for current environmental conditions and future conditions based on climate change projections, particularly for the Gulf region. Overlaid on these maps are six current socio-economic indicators and the Hazards and Vulnerability Research Institute's Social Vulnerability Index. As more than a single resilience measurement, the system's various mapping applications are descriptive of these various indicators.
8. **Coastal Resilience Index** (https://toolkit.climate.gov/tool/coastal-resilience-index). Developed by the Mississippi-Alabama Sea Grant Consortium and the National Oceanic and Atmospheric Administration's Coastal Storms Program in 2010, the index is primarily a structured guidebook for community leaders to self-assess in response to a series of yes/no questions across five physical and social categories. Affirmative responses are tabulated and placed within categories, and a qualitative scale of low to high assigned to

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each category. Other versions of the index have been developed for specific infrastructure or economic sectors (like tourism and ports), although these follow a similar guidance and introspection process rather than one based on empirical measurement.

9. **Community Assessment of Resilience Tool (CART)** (http://www.start.umd.edu/research-projects/community-assessment-resilience-tool-cart). Developed out of the National Consortium for the Study of Terrorism and Responses to Terrorism (START), CART is a community survey begun by scholars as a method for initiating community resilience building, particularly in the areas of capacity, competence, health, mobilization, and empowerment. Pfefferbaum et al. (2007) identified seven attributes of community resilience based on a workshop held by the Centers for Disease Control and Prevention and the Terrorism and Disaster Branch of the National Center for Child Traumatic Stress.
10. **Community Disaster Resilience Index (CDRI)** (https://pdfs.semanticscholar.org/ea56/1b67fb9fa11964a32e99c4da14ad32dd39de.pdf). With funding from the National Oceanic and Atmospheric Administration, Texas A&M scholars produced series of indicator sets beginning in 2010 that overlaid multidimensional capitals onto disaster stages, and these were subjected to preliminary reliability and internal and external validity tests. The resulting measurement framework was implemented in U.S. Gulf Coast counties and resulted in a series of scholarly papers and theses. No additional application has been documented to date.
11. **Community Resilience Indicators and National-Level Measures** (https://www.fema.gov/community-resilience-indicators). In 2016, the Federal Emergency Management Agency published a draft concept paper produced by an interagency project team co-led by the agency and the National Oceanic and Atmospheric Administration that outlined an approach to measuring community resilience capacity using 28 distinct indicators across 10 "core capacities," including physical infrastructure themes as well as hazard mitigation activity. The proposed framework was meant to be applicable at both the local and national levels, but no clear further revision or piloting has thus far been released.
12. **Community Resilience Manual** (https://www.fema.gov/community-resilience-indicators). In 2000, the Canadian Centre for Community Renewal produced Community Resilience Manual, a guidebook for communities to develop their own diagnostics for community resilience. The manual provides a list of questions for respondents to qualitatively assess the state of the community's social capital and cohesion (including inclusion and equity concerns), although it makes no reference to infrastructure, environment, or other physical dimensions. No specific applications have been noted.
13. **Community Resilience Planning Guide** (https://www.nist.gov/topics/community-resilience/community-resilience-planning-guide). Released by

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the National Institute for Standards and Technology in 2015 with several years of advisory review, the guide is not a measurement tool per se, but a six-step planning process that helps communities develop local resilience plans related to their buildings and infrastructure systems based on the support these provide to the community's social and economic institutions. The guide does not provide specific recommendations for measurement, but does provide some guidance regarding the subject dimensions.

14. **Community Resilience System (CRS)** (http://www.resilientus.org/recent-work/community-resilience-system). The Community and Regional Resilience Institute (CARRI) coordinated the creation of the CRS, which originated at Oak Ridge National Laboratory in 2010 by request of the U.S. Department of Homeland Security. The CRS is a qualitative process of community engagement and prioritization that reviews the knowledge base of community resilience and possible tools and resources, including the CART survey, which relies on seven community capacity and competence attributes in four domains thought to affect community resilience to disasters.
15. **Community Resilience: Conceptual Framework and Measurement** (https://www.fsnnetwork.org/community-resilience-conceptual-framework-and-measurement-feed-future-learning-agenda). The U.S. Agency for International Development commissioned an exploratory work in 2013 to review the state of community resilience measurement and propose sample indicators. The indicators are categorized into assets, social dimensions, and areas of collective action that somewhat mirror the dimensions described in this report but also include institutional resilience activities in addition to the resilient conditions that those activities should, in theory, produce. The resulting framework is less of an attempt at measurement as it is guidance for the agency on indicators of relevance to its interventions in development aid, particularly in relating community resilience to household resilience. It was considered in this assessment because of the level of detail in its indicators.
16. **Community-Based Resilience Analysis (CoBRA)** (http://www.undp.org/content/dam/undp/library/Environment and Energy/sustainable land management/CoBRA/CoBRRA_Conceptual_Framework.pdf). The United Nations Development Programme's Drylands Development Centre developed the CoBRA beginning in 2012 based on observations from a project in Ethiopia, Kenya, and Uganda with the goal of measuring resilience at the community and household levels. The tool has since been field-tested and revised. Its indicators are structured around five capitals that mirror other resilience literature, each of which is given a score tallied across indicator sets. Although the focus is on rural communities in developing contexts (with a sub-focus on food security and infrastructure), the overall structure parallels that of other measurement efforts for community resilience.
17. **Conjoint Community Resilience Assessment Measure (CCRAM)** (http://in.bgu.ac.il/en/PREPARED/Pages/ccram.aspx). Begun in 2010 by a group of

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Israeli scholars, the CCRAM integrates multidimensional indicators into a measurement instrument for community resilience after a disaster. The tool was subjected to psychometric testing that led to a 10-indicator instrument across the functional areas of leadership, collective efficacy, preparedness, place attachment, and social trust. Among all of the measurement frameworks reviewed for this report, this is the only one to measure indicators *after* an event.

18. **Disaster Resilience Scorecard**. Beginning in 2016, IBM and AECOM collaborated to produce a scorecard composed of 10 "essentials" that evolve around a checklist of activities and plans that communities should undertake to prepare for and reduce their risks to disasters. The activities address a wide range of resilience dimensions, but not as a direct result of measurement. Rather, the scorecard serves primarily as a process guide. The organization reports having utilized the scorecard in several communities via one- or two-day workshops.
19. **Disaster Resilient Scorecard for Cities** (https://www.unisdr.org/campaign/resilientcities/home/toolkitblkitem/?id=4). The United Nations International Strategy for Disaster Risk Reduction developed the Disaster Resilient Scorecard for Cities in 2014 for cities to establish a baseline measurement of their current level of disaster resilience and identify priorities for investment. The scorecard requires ranking across 85 criteria grouped primarily into a combination of functional capacity measures (planning organization, response and recovery functions, for example) with additional indicators for risk assessment and physical infrastructure and environment. The focus of the scorecard, then, is on the public sector's operations, and qualitative assessments are scaled (from 0 to 5) and tabulated. The scorecard has been piloted in many cities (all outside the United States) but, because of the subjective data collection and analysis, has not been used to compare across cities. It has not undergone reliability and validity testing.
20. **Earthquake Recovery Model** (https://www.spur.org). The San Francisco Planning and Urban Research Association (SPUR) published an estimated time frame for recovery of various infrastructure facilities after an earthquake scenario (SPUR, 2008). The estimates are summaries of professional judgment (rather than being based on actual post-disaster recovery data) and are not tied to any specific indicator related to the multiple dimensions of resilience. No further analysis or revision has been conducted since the original publication.
21. **Evaluating Urban Resilience to Climate Change** (https://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=322482). The Environmental Protection Agency produced an urban resilience assessment protocol in 2016, Evaluating Urban Resilience to Climate Change, that incorporated dozens of indicators across eight sectors (with an emphasis on environmental and infrastructure sectors). To overcome challenges in the qualitative indicators,

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thresholds were proposed by which communities' responses could be scaled. The framework was piloted in two communities but has not been revised or fielded further, as of early 2019.

22. **Flood Resilience Measurement Framework** (https://www.zurich.com/en/corporate-responsibility/flood-resilience/measuring-flood-resilience). Produced by the insurer, Zurich Insurance Group, in 2014, the Flood Resilience Measurement Framework addresses 88 indicators across five capitals similarly defined as those presented in this report, and tagged by disaster stage, resilience property, and theme. The framework is focused on pre-disaster conditions in relation to flood events only, as opposed to being an overarching resilience measure. Data for the indicators come from household surveys, focus groups, key informant interviews, community meetings, and third party sources. These qualitative data are scaled to tabulate individual scores that are then translated into numeric values per capital. The framework has been pilot-tested in more than 100 communities worldwide (including in two National Academies' Resilient America Roundtable pilot communities).
23. **Framework for Community Resilience** (http://www.ifrc.org/Global/Documents/Secretariat/201501/1284000-Framework%20for%20Community%20Resilience-EN-LR.pdf). The International Federation of the Red Cross produced the Framework for Community Resilience in 2014, an exploratory framework for community resilience that focuses on objectives within a purposeful theory of change, and proposed sample indicators for demonstrating the efficacy of interventions designed around that theory. The indicators and, to a lesser extent, the objectives map onto multiple dimensions of resilience. However, the framework appears to have been a strategy exercise that has not been employed either in a specific community or for a specific intervention.
24. **Indicators of Disaster Risk and Risk Management** (http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=35177671). In 2010, the Inter-American Development Bank produced a report suggesting a framework across member nations that mirrors other resilience measurement efforts. However, the proposed four indexes were tabulations across core functional areas: disaster deficit (economic) risk, aggregate local risks, risk management, and vulnerability. These indicators were structured to support investment and prioritization. Beyond the analysis performed for the report, there is no evidence of further revision or application.
25. **National Health Security Preparedness Index** (https://nhspi.org/explore-the-index). Originally developed by the Centers for Disease Control and Prevention as an exploratory tool to improve the awareness of health security and preparedness, the National Health Security Preparedness Index has since been revised and employed annually across the United States by the Robert Wood Johnson Foundation since 2013. In the 2016 version, 134 individual measures were analyzed including a group of 18 measures defined as foundational capabilities. The focus of the indicators is on functional preparedness

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of public health entities (a refined mirror to some community resilience measurement's attempts to capture public-sector capacity).

26. **PEOPLES Framework** (http://peoplesresilience.org). First published by the National Institute of Standards and Technology in 2010, the framework represents an aggregate of seven categories of community indicators that provide a theoretical snapshot across multiple dimensions. Though there is no clear operational metric or data collection system proposed, each category suggests a wide range of indicator themes. There is currently no clear use of the framework beyond its serving as helpful guidance for the categories in question.
27. **Resilience Capacity Index (RCI)** (http://brr.berkeley.edu/rci). Developed by Foster (2011) and promoted by the research network, Building Resilient Regions, the RCI is a single value for U.S. metropolitan regions that summarizes 12 social and economic indicators given equal weight, with no additional reliability or validity testing. Each indicator as well as the overall index scores are then ranked across the sample of 361 areas. No additional revision or analysis has been produced.
28. **Resilience Index Measurement and Analysis (RIMA)** (http://www.fao.org/3/a-i5665e.pdf). In 2010, the United Nations Food and Agriculture Organization produced a measurement framework for resilience that focused on social service delivery and access. Grounded in food security and developmental aid literature, the tool was applied at the city level for a range of communities undergoing significant service gaps or challenges. The tool was piloted in at least six communities but has not undergone additional revision or fielding.
29. **Resilience Inference Measurement (RIM)** (https://www.unisdr.org/campaign/resilientcities/home/toolkitblkitem/?id=11). Another scholarly approach to community resilience measurement (Lam et al., 2016), RIM models attempt to quantify resilience across three "elements" (exposure, damage, and recovery indicators) to denote vulnerability and adaptability. In contrast to other measurement frameworks, the authors of RIM propose a reassessment of core independent variables across multiple dimensions (typically starting with 25 theoretically grounded variables) in every context, thereby limiting generalizability. The model also attributes change in the development variables solely to the selected independent variables, thereby likely omitting other causal explanations.
30. **Resilience Measurement Index (RMI)** (http://www.anl.gov/grid/project/resilience-measurement-index-rmi and http://www.ipd.anl.gov/anlpubs/2013/07/76797.pdf). The Infrastructure Assurance Center at Argonne National Laboratory, in partnership with the Protective Security Coordination Division of the U.S. Department of Homeland Security, developed the RMI to characterize the impact and response resilience of critical infrastructure with respect to all hazards. Released in 2013, the index is intended to

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support decision making related to risk management, disaster response, and maintenance of business continuity.

31. **Resilience Scorecard** (http://coastalresiliencecenter.unc.edu/wp-content/uploads/2016/02/Berke_et_al._best_paper_JAPA_2015.pdf and http://ifsc.tamu.edu/getattachment/News/July-2017/Plan-Integration-for-Resilience-Scorecard-Guideboo/Scorecard-(1).pdf.aspx). Developed by urban planning scholars to project plans' impacts on a community's physical and social vulnerability to hazards (Berke et al., 2015), the Resilience Scorecard relies on an index derived from 11 social indicators at the census block group level and two environmental hazard indicators. The scorecard is not meant as measurement of resilience per se, but as an assessment tool for planning districts' vulnerability gaps.
32. **Resilience United States (ResilUS)** (https://www.researchgate.net/publication/233714675_ResilUS_A_Community_Based_Disaster_Resilience_Model). ResilUS is a loss-estimation simulator devised by scholars (Miles and Chang, 2007) to project losses (like the Federal Emergency Management Agency's Hazus) and recovery time in communities after disaster scenarios based on existing social, economic, and infrastructure indicators similar to those used in frameworks that measure resilience capacity in pre-disaster and general conditions. Like the San Francisco Planning and Urban Research Association's framework, ResilUS is not meant to measure resilience more broadly as defined in past National Academies' publications; rather, it focuses on the post-disaster recovery time exclusively.
33. **Rural Resilience Index (RRI)** (https://rdrp.jibc.ca/rural-resilience-index-rri and http://journals.sagepub.com/doi/abs/10.1177/0002764214550297). The RRI is a qualitative resilience self-assessment process and toolkit devised for rural communities by Canadian scholars (Cox and Hamlen, 2014), designed to address one resilience dimension (social cohesion) and one public function (emergency management). A series of yes/no questions are meant to be answered by citizens, tallied, and scored into a summative index. It has been field tested in a handful of Canadian cities though its ongoing use is unclear.

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Appendix D

Communities the Committee Visited

As part of its ground truthing of community resilience efforts in communities, the committee conferred with eight communities across the country.

BATON ROUGE, LOUISIANA

Baton Rouge's most recent disaster—a pluvial flood in August 2016—produced catastrophic flooding in the region. Prior to this event, the city had experienced an influx of people displaced by disasters, most notably by Hurricane Katrina in 2005 (Grier, 2005). Since the 2016 flood, Baton Rouge has undertaken efforts to address post-disaster recovery challenges (e.g., housing shortages, rent increases) and repetitive flooding in the city. Baton Rouge's comprehensive plan, "Future BR," provides new building regulations that promote resilience. The city is also working with the Center for Planning Excellence on infrastructure resilience and with Louisiana State University to develop watershed-wide storm runoff models and storm scenarios to better manage the potential impacts in the region.

For more information, see:

- Baton Rouge Comprehensive Plan: Future BR: https://www.brla.gov/662/FUTUREBR
- Baton Rouge Hazard Mitigation Plan, 2016: https://www.brla.gov/1370/Hazard-Mitigation-Plan
- Coastal Protection and Restoration Authority Flood Risk and Resilience Viewer tool: http://coastal.la.gov/flood-risk-resilience-viewer/

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- Louisiana Smart Growth Summit:
  https://summit.cpex.org/resilience-as-a-framework

GULFPORT, MISSISSIPPI

Gulfport, a coastal community, was devastated by Hurricane Katrina in 2005, with more than 9,500 houses damaged or destroyed. The city received more than $300 million in federal aid to rebuild after Katrina. Today, Gulfport has a new harbor, new infrastructure, restored historic buildings, and a downtown with new restaurants and urban art (Brown, 2015). The 2010 BP oil spill had a negative impact on the economy, livelihoods, and public health along the Gulf Coast, including Gulfport (Gill, Picou, and Ritchie, 2012; Gill et al., 2014; Lee and Blanchard, 2010, 2011; Ritchie, Gill, and Long, 2018). Community stakeholders shared with the committee how Gulfport is focused on preparedness and long-term recovery that will support the financial strength of local city government.

For more information, see:

- Gulfport 2030 Comprehensive Plan:
  http://media.sunherald.com/static/images/graphics/0331%20Gulfport%20Comprehensive%20Plan.pdf
- Gulfport Hazard Mitigation Flood Protection Plan, 2013-2017:
  http://msrestoreteam.com/docs/Gulfport%20Hazard%20Mitigation%20Plan_2013.pdf
- Gulfport Resilience Essays:
  http://www.resilientus.org/publications/gulfport-resilience-essays

MINOT, NORTH DAKOTA

The City of Minot's resilience initiatives are shaped by the severe flooding in 2011 when the Souris River overtopped levees and caused the evacuation of 12,000 residents. More than 3,100 homes were damaged or destroyed, and the surrounding rural areas suffered losses of cattle and crops (City of Minot, 2013; RF, 2016). Minot is an isolated, tightly knit community of about 50,000 people with a strong sense of community self-reliance and a neighbor-helping-neighbor spirit. In 2016, the city received a $74 million Community Development Block Grant through the Department of Housing and Urban Development's National Disaster Resilience Competition. The city is using this grant to buy out properties, develop a downtown gathering space, develop a vulnerable population action plan and family shelter, build affordable housing, and create a Souris River Decision-making Tool for river management modeling (City of Minot, 2015). The City of Minot is in transition from flood recovery to building community resilience with support for its resilience initiatives from local residents and state and federal governments.

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For more information, see:

- City of Minot Comprehensive Plan, 2012: https://www.minotnd.org/233/Comprehensive-Plan
- Pathway to a Resilient Future: Housing, Economy and the River that Connects Us, 2015: https://www.minotnd.org/DocumentCenter/View/617/NDRC_Phase1_Submissionpdf?bidId=
- Ward County, ND Hazard Mitigation Plan, 2017: https://www.minotnd.org/646/Hazard-Mitigation-Plan

NEW ORLEANS, LOUISIANA

Hurricane Katrina in 2005 was the biggest acute shock in New Orleans' recent history, resulting in over 1,000 deaths, more than one million people displaced, and about $151 billion in damage (Plyer, Shrinath, and Mack, 2015). Since then, New Orleans has undertaken several initiatives to build community resilience. In 2013, the city became a founding member of the Rockefeller Foundation's 100 Resilient Cities initiative and released its first resilience strategy, Resilient New Orleans, in 2015. This strategy provides a roadmap for building urban resilience and is central to ongoing initiatives (City of New Orleans, 2015).

As part of its resilience-building efforts, New Orleans is incorporating a broader set of shocks and stresses into its emergency management, planning, and preparedness activities. In 2014, the city created the Network for Economic Opportunity to connect unemployed and at-risk jobseekers to the opportunities created by funded projects such as the airport. Within the Regional Planning Commission, New Orleans led the regional Resilience Committee (2015) to integrate resilience thinking across neighboring jurisdictions into the existing work of economic development, environmental planning, and transportation planning in greater New Orleans. Other initiatives include a climate action plan (City of New Orleans, 2017); adoption of the principles and goals of the Paris Climate Agreement; membership to the Global Covenant of Mayors for Climate and Energy; creation of the New Orleans Redevelopment Authority Community Adaptation Program; establishment of the Adopt a Catch Basin program; and wetland restoration.

For more information, see:

- New Orleans Preliminary Resilience Assessment, 2015: https://www.nola.gov/resilience/resources/nola-preliminary-resilience-assessment-6-15
- Resilient New Orleans Strategic Actions to Shape Our Future City, 2015: http://resilientnola.org/wp-content/uploads/2015/08/Resilient_New_Orleans_Strategy.pdf

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- Plan for the 21st Century: New Orleans 2030:
  https://www.nola.gov/city-planning/master-plan
- Hazard Mitigation Plan: City of New Orleans, LA, 2015:
  https://www.nola.gov/hazard-mitigation

NEW YORK, NEW YORK

At the time of the committee's visit, New York City was approaching the 5-year anniversary of Hurricane Sandy, which struck the east coast in October 2012. Sandy resulted in 43 deaths and $19 billion in damage (City of New York, 2013). Nursing homes were evacuated and more than one million children were out of school for a week.

In 2013, New York City joined the Rockefeller Foundation's 100 Resilient Cities initiative and published its resilience strategy in 2015, which guides the city as it addresses challenges around climate change, extreme heat, hurricanes, flooding, sea level rise, and severe storms. According to city government staff, New York City has a $20 billion portfolio of resilience projects; $15 billion is federally funded. The city's plan, "One New York: The Plan for a Strong and Just City" (OneNYC), has four visions focused on sustainability, resilience, equity, and growth. The city is considering ways to finance and continue its resilience work, through resilience projects and by embedding resilience into other city actions and plans.

For more information, see:

- OneNYC: The Plan for a Strong and Just City:
  https://onenyc.cityofnewyork.us/#content
- NYC Hazard Mitigation Plan, 2016:
  https://www1.nyc.gov/site/em/ready/hazard-mitigation.page
- MTA Climate Adaptation Task Force Resiliency Report, 2017:
  http://web.mta.info/sustainability/pdf/ResiliencyReport.pdf

PINE RIDGE RESERVATION, SOUTH DAKOTA

Pine Ridge Reservation has experienced several disasters in recent years including the May/June 2015 windstorm; September 2016 tornado; December 2016 winter storm; July 2017 tornado; and severe storms in August 2017. Pine Ridge Reservation has the lowest life expectancy and some of the poorest communities in the United States. Some of its most pressing priorities include tackling the chronic housing shortage, addressing day-to-day crises, and spurring economic development. The Pine Ridge Long-Term Recovery Committee, formed in early 2016, consists of more than 100 local, state, and national partners who are working together to repair and rebuild homes, as well as meet other disaster-related needs of residents. Local tribal members are also taking action. For example, The

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Guardians is a grassroots effort composed of volunteers who carry out a range of initiatives, including emergency response during disasters (Rooks, 2016).

For more information, see:

- Partnership With Native Americans, "South Dakota: Pine Ridge Reservation": http://www.nativepartnership.org/site/PageServer?pagename=PWNA_Native_Reservations_PineRidge
- Slate.com, Feb 20, 2014, "A Photographer's Moving Tribute to the Pine Ridge Reservation": https://slate.com/culture/2014/02/aaron-huey-photographs-the-pine-ridge-reservation-in-south-dakota-in-his-book-mitakuye-oyasin-photos.html

RAPID CITY, SOUTH DAKOTA

Rapid City was devastated by the Black Hills flood of 1972. Since then, the city has implemented mitigation measures to protect against future floods. In early October 2013, Winter Storm Atlas, an early-season blizzard, hit the South Dakota region. The storm's severity and unexpected timing for the season left the region with devastating livestock and agricultural losses, power and heat outages, damaged homes and buildings, and debris that obstructed transportation. A few months later, in April 2014, an ice storm hit the city, creating many of the same challenges as Atlas. To address its many weather-related events, the City of Rapid City has incorporated resilience planning and zoning components into its comprehensive plan, highlighting the community's seven core values: growth; livability; health and wellbeing; efficient transportation and infrastructure systems; economic stability; recreation and culture; and responsive, effective governance (Rapid City, 2014).

For more information, see:

- Plan Rapid City: Our Community. Our Future, 2014: http://planrapidcity.com/images/uploads/documents/Rapid_City_Comprehensive_Plan_Adopted_April_2014_with_Maps__Appendices.pdf

WAVELAND, MISSISSIPPI

Located on the Gulf Coast, Waveland was devastated by Hurricane Katrina. The community's population is still below its pre-Katrina level, its recovery further hindered by the 2010 BP oil spill. The community is still in the process of rebuilding its main business district and has made strides to update its pipe and drainage infrastructure to newer materials, harden its communication systems, and improve its plans and procedures for emergency response.

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For more information, see:

- About Waveland:
  http://waveland.ms.gov/about-waveland
- City of Waveland Local Hazard Mitigation Plan, 2013:
  http://waveland.ms.gov/wp-content/uploads/2016/12/LocalHazard MitigationPlan2013r1.pdf
- Ground Zero Hurricane Museum:
  https://www.wavelandgroundzero.com

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Appendix E

Other Communities Considered by the Committee

As part of its ground truthing of community resilience efforts in communities, the committee considered community work being undertaking by the National Academy of Sciences' Resilient America Program and the National Institute of Standards and Technology. The Resilient America Roundtable launched a community pilot program in 2014 that partnered with local stakeholders in four communities—Cedar Rapids, Iowa; Central Puget Sound region, Washington; Charleston, South Carolina; and Tulsa, Oklahoma—to enhance and build their resilience. In 2015, the National Institute of Standards and Technology worked with the Boulder County Collaborative to develop a Resilient Design Performance Standard.

BOULDER, COLORADO

Colorado experiences a variety of disasters including blizzards, tornadoes, wildfires, floods and earthquakes. After the September 2013 floods, the state turned its attention to resilience building and developed the Colorado Resiliency Framework,[1] which became the marching orders for reconstruction after the floods. Boulder became a member of the Rockefeller 100 Resilient Cities initiative in 2014 and released its resilience strategy in 2016. Two of its resilience challenges are: (1) the exacerbation of natural hazards (e.g., flooding, wildfires) from climate change, and (2) the link between ecological and social stresses with hazards and their negative impact on each other. Box 2-4 (Chapter 2) discusses

[1] See https://sites.google.com/a/state.co.us/coloradounited/resiliency-framework?mobile=true.

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the implementation of the National Institute of Standards and Technology Community Resilience Planning Guide in Boulder County.

CEDAR RAPIDS, IOWA

Cedar Rapids' devastating flood of 2008, a Presidentially Declared Disaster, was the defining disaster for the city. The Cedar River crested just above 31 feet, 12 feet higher than the previous record, resulting in overtopped levees and major damage to homes and businesses. The floodwaters devastated more than 10 square miles of the city and displaced about 10,000 residents.[2] More than $5.4 billion in flood losses were reported, and city buildings outside of the 500-year floodplain (e.g., Linn County Sheriff's Office and Mercy Medical Center) were seriously damaged. Since the 2008 floods, Cedar Rapids has made significant progress toward flood mitigation and recovery (e.g., by installing a comprehensive flood control system),[3] and continues its efforts to become more prepared and build resilience to future floods and other hazards. In 2016, the Cedar River crested at 21.97 feet, the second-highest river crest in the city's history. The city was well prepared and weathered that flood relatively unscathed.

CENTRAL PUGET SOUND REGION, WASHINGTON

The Central Puget Sound Region includes King, Kitsap, Pierce, and Snohomish counties. Communities in the region face a variety of hazards including earthquakes, snow, ice, landslides, sea level rise, flooding, windstorms, and wild fires. The 2014 Oso landslide[4] destroyed 40 homes, dammed the North Fork Stillaguamish River, and flooded numerous other homes and buildings; 43 residents lost their lives (USGS, 2015). The Hanukkah Eve windstorm in 2006 resulted in 14 deaths, millions of people without electricity for days, and hundreds of millions of dollars in damage (Wilma, 2006). And, the 6.8 magnitude Nisqually Earthquake in 2001 left about 400 people injured, damaged and destroyed buildings and roads, and resulted in billions of dollars in damage. Efforts are under way in the region to create a fully operational Earthquake Early Warning System (a.k.a., ShakeAlert™).[5] To reduce flood risk, Pierce County has partnered with a number of agencies and organizations to complete floodplain remediation projects as part of its Floodplains for the Future Program.[6] And the Snohomish County's Sustainable Lands Strategy is a multistakeholder effort of municipal,

[2] See http://www.cedar-rapids.org/discover_cedar_rapids/flood_of_2008/2008_flood_facts.php.

[3] See http://www.cedar-rapids.org/local_government/departments_g_-_v/public_works/cedar_river_flood_control_system.php.

[4] See http://old.seattletimes.com/flatpages/local/oso-mudslide-coverage.html.

[5] For information about ShakeAlert™: https://www.shakealert.org.

[6] See http://www.co.pierce.wa.us/4684/Floodplains-for-the-Future.

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state, federal, and tribal partners working to identify solutions that are beneficial for fishing, farming, and flooding.[7]

CHARLESTON, SOUTH CAROLINA

Since the landmark disaster of Hurricane Hugo in 1989, Charleston has experienced several notable flood events: historic rainfall in October 2015, Hurricane Matthew in 2016, and Hurricane Irma in 2017. In recent years, the city has demonstrated a commitment to flood resilience. For example, in December 2015, the city identified sea level rise as a top priority in its first Sea Level Rise Strategy. Additionally, a volunteer group of individuals representing public, private, and nonprofit organizations created the Charleston Resilience Network.[8] The network is working to enhance resilience in the community by sharing information, educating stakeholders, and fostering a unified strategy. The Charleston Resilience Network is also working on resilience projects including Building Community Resilience to Water-Related Hazards in the Charleston, SC Region and Development of Multi-hazard Coastal Resiliency Assessment and Adaptation Indices and Tools for the Charleston, SC Region. The city hired its first chief resilience officer in early 2017.

TULSA, OKLAHOMA

Tulsa experienced a devastating flood in 1984 that resulted in 14 deaths and $180 million in damage. As a result, the city implemented a major flood control program that included buyouts, comprehensive stormwater management, and a flood control system.[9] In 2014, the city became a member of the Rockefeller Foundation's 100 Resilient Cities initiative. The success of the flood control program has allowed the city to now focus on other challenges and priorities. In a state where city budgets are largely based on yearly sales-tax revenues, these revenues can be a primary determinant for how and whether a community is able to take action to build resilience to hazards. In recent years, Tulsa has experienced budget fluctuations in its yearly sales tax revenues, which can jeopardize the city's ability to provide critical services. Thus, economic resilience is one of the city's key priorities.

[7] For information about the Sustainable Lands Strategy, see https://snohomishcountywa.gov/2194/37813/Sustainable-Lands-Strategy.

[8] For more information about the Charleston Resilience Network, see http://www.charlestonresilience.net.

[9] See https://www.cityoftulsa.org/government/departments/engineering-services/flood-control/flooding-history.

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