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Dam and Levee Safety and Community Resilience: A Vision for Future Practice

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DAM AND LEVEE SAFETY

AND COMMUNITY RESILIENCE

A VISION FOR FUTURE PRACTICE

Committee on Integrating Dam and Levee Safety and Community Resilience

Committee on Geological and Geotechnical Engineering

Board on Earth Sciences and Resources

Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
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Preface

Late in 2005, in the aftermath of Hurricane Katrina, U.S. newspapers were filled with speculation as to whether New Orleans would continue to exist as a great and unique American city. Levee and floodwall failure had inundated large parts of the city and resulted in more than 1,500 deaths and catastrophic damage to property and the economy. In 2011, extreme amounts of precipitation, inadequate levees, and possible mismanagement of reservoirs contributed to widespread flooding around Bangkok, Thailand. More than 500 deaths have been associated with that flood,[1] and the closing of more than 1,000 industrial facilities had severe repercussions for global supply chains in the electronics and automotive industries.[2] These two incidents occurred half a world and 6 years apart, but they shared a set of facts: neither city was adequately prepared, had appropriate measures in place to mitigate damage once flooding occurred, or seemed able to recover quickly; and neither city proved particularly resilient in the face of what were somewhat foreseeable circumstances.

Resilience has long been a major topic in the natural-hazard literature and is defined in this report as the ability of a system to absorb disturbance and quickly return to normal or a new normal while maintaining its identity and ability to function. In the case of earthquakes, for example, there is convincing evidence that building community resilience through preparedness, risk communication, response and recovery planning, and adaptation substantially reduces short-term and long-term effects of earthquakes. It is reasonable to assume that the same would be true for flooding events, but many questions arise: What actions increase resilience? Who should take those actions? How can they be motivated to do so? How can one monitor progress and success in building resilience? And, most relevant to the present study, how can the Federal Emergency Management Agency (FEMA) use its programs and networks to promote increased community resilience?

[1] See www.bbc.co.uk/news/world-asia-15610536.
[2] See www.nytimes.com/2011/11/07/business/global/07iht-floods07.html.

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In its search for answers, FEMA asked the National Research Council (NRC) to convene a committee to determine how dam and levee safety programs can be broadened to include activities that enhance community and regional preparation for, response to, mitigation of, and recovery from infrastructure failure. A committee was formed in early 2011 and included a wide array of disciplines, such as engineering, economics, planning, natural-hazard studies, hazard insurance, emergency management, and sociology.

Not surprisingly, committee members quickly discovered that, although they shared long experience and deep interest in the subject, they were accustomed to working within rather different paradigms and vocabularies. Consequently, members devoted much time early in the study to learning to understand one another. The committee noted that its own communication difficulties could be considered a microcosm of the broader communication issues that every community of diverse stakeholders will confront as it attempts to build resilience.

This report describes a tool for assessing stakeholder engagement that can also gauge and document a community's progress toward greater resilience. As the committee worked to understand and develop this into a tool useful at the community level, the tool itself promoted communication among the members and eventually helped the committee reach its consensus conclusions. By extension, the tool should serve the same purpose in a community, facilitating communication as stakeholders strive to build resilience. Many tools are available for increasing community resilience, but the Maturity Matrix for Assessing Community and Stakeholder Engagement emerges as an instrument for organization, communication, and assessment—a "tool of tools."

Before embarking on the study, however, the committee had to understand the meaning and intent of the statement of task, particularly as it describes the problem confronting the sponsor. This consideration was helped greatly by early conversations with Dr. Sandra Knight, FEMA deputy associate administrator for mitigation. Dr. Knight's presentation at the first meeting emphasized several ideas that would become central themes of the study: the notion of the "whole community" as the locus of action, the importance of an integrated approach to reducing risk, and FEMA's need to find ways to motivate change through its existing dam and levee safety programs. In addition to Dr. Knight's assistance, the committee is also grateful to FEMA's James Demby for his advice and support at various critical points in the study.

The committee met four times over an 8-month period: twice in Washington, D.C., and twice in Irvine, California. In the course of those meetings, the committee consulted with a number of dam and levee engineering, management, and safety experts. They included Sandra Knight of FEMA; James Gallagher, Jr. of the New Hampshire Department of Environmental Services; Yazmin Seda-Sanabria of the U.S. Army Corps of Engineers Critical Infrastructure Protection and Resilience Program; Steve Verigin of GEI Consultants (former chief of the California Department of Water Resources Division of Safety

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of Dams); Kurt Rinehart of the Miami, Ohio, Conservancy District; Dennis Mileti of the University of Colorado; and Richard Pineda of the California Department of Water Resources. The committee is grateful to all these individuals for their thoughtful presentations and thought-provoking discussions.

Other persons attended open sessions of committee meetings and provided input. Numerous outside experts were consulted by individual members over the course of the study as the committee deliberated its task and prepared its report. Their input provided much to consider and contributed greatly to the final product

The committee had numerous occasions to be grateful for the exceptional competence and efficiency of the NRC staff members assigned to this project. Complicated logistical arrangements were handled with ease and good humor by Chanda Ijames, senior project assistant. Jason Ortego, research associate, was responsible for completing numerous research assignments, usually required in a matter of days, and he always exceeded our expectations.

An avid reader of NRC report prefaces will have seen numerous references to the high quality of its staff directors, often noting substantive contributions to fulfilling tasks in addition to managing the myriad activities that go into these studies and, finally, producing the final reports. But our experience went beyond expectations. Our staff director, Sammantha Magsino, senior program officer, served as technical resource, fact-checker, inspiration, author, editor, and taskmaster. She was repeatedly able to turn vigorous discussion into consensus, scattered notes into coherent text, and rambling discourse into disciplined thinking. Samm made the committee's challenging task rewarding and the chair's work manageable.

From the first meeting of this committee, there was no doubt about members' passion for the subject of community resilience, born of long experience with floods and their aftermath. But the transformation of their passion into concrete suggestions for FEMA, as it builds strategies for community resilience into dam and levee safety programs, proved complex and challenging. We believe that we have made a good start, but there is more to be done.

John J. Boland
Chair

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Acknowledgment of Reviewers

This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of the independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of 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 participation in the review of this report:

Gerald E. Galloway, University of Maryland, College Park
John R. Harrald, Virginia Polytechnic and State University, Alexandria
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Alessandro Palmieri, The World Bank, Washington, D.C.
Ricardo Pineda, California Department of Water Resources, Sacramento
Paula Scalingi, Bay Area Center for Regional Disaster Resilience, Pleasanton, California

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by John Christian, Consulting Engineer, Burlington, Massachusetts. Appointed by

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the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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Summary

The consequences of dam and levee failure on physical and social infrastructures reach far beyond the flood zone, making a comprehensive approach to dam and levee safety that extends beyond the core traditional goals of safety programs necessary. At the request of the Federal Emergency Management Agency (FEMA), the National Research Council convened a panel of experts to consider how dam and levee safety, in concept and practice, can be expanded to promote the core values of the FEMA mission.[1] The study is intended to aid development of initiatives that help community decision makers reduce risk of, and increase community resilience to, dam or levee failure (see Box S.1 for the statement of task). Two underlying principles are the foundation of discussion in this report. The first is that although the likelihood of uncontrolled water flow from dams and levees can be reduced in most cases, failures will still occur. The second principle is that communities can prepare for and mitigate the consequences of failure and can become adaptable in their responses and recoveries. To enhance community resilience, communities (including dam and levee safety professionals) can institute adaptive processes chosen through collective and collaborative efforts on the basis of mutual appreciation of community priorities, hazards, and consequences.

This report will be of interest to a broad audience, but much of the discussion is directed to dam and levee professionals in both private and public infrastructure safety programs, and at all levels of government. Dam and levee safety professionals include infrastructure owners, operators, and regulators, the majority of whom are technical experts in such areas as geotechnical, geologic, hydrologic, hydraulic, and civil-structural engineering. They are defined by their occupations and organizational responsibilities, not by proximity to dams or levees or by exposure to risk. Because a large percentage of dam and levee infrastructure is privately owned, many professionals are not government employees. These individuals

[1]See www.fema.gov/about/.

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Dam and Levee Safety and Community Resilience: A Vision for Future Practice

BOX S.1
Statement of Task

An ad hoc committee of the National Research Council will analyze and provide conclusions on how dam and levee safety programs may be broadened to include community- and regional-level preparation, response, mitigation, and recovery from potential infrastructure failure. The study will examine

- Holistic systematic approaches to safety analysis. Links between the geotechnical, geologic, hydrologic and hydraulic, and civil-structural engineering aspects of safety and the risks to communities and other stakeholders will be identified. The committee will consider how incorporating mitigation, preparedness, response, and recovery into safety programs can enhance long-term community- and regional-level resilience.
- Communication and engagement. The committee will describe current practices for identifying local and regional stakeholders, and for collecting and disseminating information among them, including how concerns are reassessed as infrastructure conditions change, safety issues emerge, and community needs and interests evolve. Conclusions regarding the improvement of these practices will be provided.
- Decision-making and decision-support systems. The committee will summarize how safety information, including stakeholder input, and inspection, monitoring, analysis, and impacts data are used in safety programs for decision making for both infrastructure management and improving community- and regional-level resilience against the primary (e.g., inundation) and secondary impacts (e.g., regional power loss) of infrastructure failure. The committee will provide conclusions regarding how stakeholder input may be incorporated into the design of safety and communication decision processes.

The committee will identify tools, products, and guidance that could be developed at the federal level to address the issues above. The human behavioral drivers that may promote or inhibit the expansion of dam and levee safety programs to promote community resilience will be considered. The committee's conclusions will assist the federal government in developing a more comprehensive and effective dam and levee safety program, but no policy or funding recommendations will be made.

ultimately will be responsible for improving dam and levee safety practice. The report communicates, especially to them, concepts of community resilience and the roles of professionals in increasing community resilience.

This report is not a comprehensive discussion of community resilience, nor does it offer a general framework for building community resilience. It is a discussion of how dam and levee safety professionals at the community level can become part of broader resilience-focused community efforts, and how professionals at higher (state and federal) levels may assist them. It describes the holistic approach and some of the major changes in safety

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engineering practice required of many dam and levee professionals in terms that will be informative to them. Once a holistic approach is adopted by a safety program, safety professionals will need to apply it to their areas of expertise and responsibility as appropriate, given the unique qualities of the physical and social infrastructures of affected communities.

The committee's major conclusions related to the concepts and processes necessary to bring about these changes are presented. Each conclusion builds on the preceding. A framework for process selection is provided, but because operations to enhance safety and resilience will be necessarily unique for each community, specific steps for enhancing resilience are not provided. The first three conclusions define community, community resilience, and the responsibility of dam and levee professionals with respect to resilience. The fourth conclusion addresses policy and practice with respect to information access. The fifth and sixth conclusions relate to collaborative risk management and approaches. The seventh summarizes necessary shifts in safety program practice and culture. The eighth addresses how the federal government might assist. The ninth and tenth conclusions address assessment of safety program and community processes for enhancing resilience and a framework for doing so.

DAM AND LEVEE SAFETY GOVERNANCE

Governance of dams differs from levee governance. Over 30 years, the National Dam Safety Program (NDSP) has assisted in enhancing state dam safety programs which regulate individual dam owners and their programs. As a result, safety is often equated with reducing the likelihood of dam failure. However, many state programs are unable to meet NDSP objectives, and individuals, property, and institutions are at risk for direct and indirect consequences of failure. A lack of unified standards and policies across the regulatory community causes many dam owners to grapple with conflicting standards that often ignore downstream issues and effects, and that do not address community-wide risk.

In contrast with dam programs, there is little governance or guidance for levee programs that are outside the federal domain where the Army Corps of Engineers provides some specific guidance. The National Flood Insurance Program (NFIP)—managed by FEMA to map flood-prone areas, establish floodplain management regulations, and provide flood insurance—has established a 100-year base flood elevation criterion that has become a de facto standard in the absence of more definitive guidance. However, development close to levees may increase risk to people and property, with little or no liability or accountability on the part of developers. This increases the dilemma for levee infrastructure owners and managers.

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RESILIENCE AND COMMUNITY

The terms *resilience* and *community* may be defined differently by engineers, social scientists, emergency managers, and others. The ability to institutionalize many of the suggestions in this report depends, in part, on a common understanding of these terms. This report uses a definition of resilience consistent with that of FEMA: the ability of a system to absorb change and disturbance while maintaining its basic structure and function. Resilience, however, does not imply that a system will necessarily return to its original state after an adverse event. Because communities are not static systems, resilient communities are those able to adapt to changing conditions, continue to meet the critical needs of community members, and maintain a sense of community identity.

Conclusion 1. The dam and levee community comprises dam and levee safety professionals, and other individuals, groups, and institutions that benefit from the continued and safe functioning of dam and levee infrastructure—whether or not those benefits are recognized by the individual community members.

Community, as defined in this report, includes all persons and organizations exposed to direct consequences (the physical effects of inundation such as loss of life or property) or indirect consequences (such as financial burden, loss of public services, or loss of benefits from the ecosystem) of dam or levee failure. Indirect consequences of failure may affect those outside the geographic vicinity of dam or levee infrastructure or floodplains, defined as stakeholders in this report. Interested and affected parties therefore include dam and levee safety professionals, persons and property at risk, social-economic systems (such as governance organizations, emergency management offices, political and social networks, and environmental and cultural resources), and members of the wider economy. The dam or levee community could, in some cases, extend regionally and globally and include manufacturing interests whose supply chains may be disrupted, financial institutions, commercial risk managers, the insurance market, and FEMA (as manager of the NFIP).

Conclusion 2. Community resilience is a community effort, and dam and levee safety professionals are part of the community.

As a system, a community depends on the proper functioning of its components. Community resilience depends on the interactive functioning of those components, especially during times of stress. Dams and levees, as part of the nation's critical infrastructure, contribute to the functioning of many communities. The expertise and practice of dam and levee professionals, as the designers and caretakers of dams and levees, are critical for community resilience. However, dam and levee infrastructure also depends on other com-

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ponents of the community, and dam and levee professionals are interconnected with the communities they serve and often live in.

Conclusion 3. Those subject to the direct or indirect impacts of dam or levee failure are also those with the opportunity to reduce the consequences of failure through physical and social changes in the community, community growth planning, safe housing construction, financial planning (including bonds and insurance), and development of the capacity to adapt to change.

Understanding the purpose, benefits, and associated risks of dam and levee infrastructure can motivate a community to assess, anticipate, minimize, and absorb potential threats over the short and long terms. Although those who suffer the consequences of infrastructure failure may have little or no control over the infrastructure, everyone can help reduce the consequences, if not the risk, of failure. Understanding individual and organizational roles and responsibilities with respect to personal, financial, and other types of risk associated with potential dam and levee failure scenarios is a starting point for enhancing community resilience. Safety and resource management programs can provide safety and risk information related to dam and levee functions and can participate in decision making that helps a community prepare, mitigate, respond, recover, and adapt in response to potential infrastructure failure. In turn, the technical decisions (e.g., to raise or lower water levels under given circumstances) may be more supportive of community resilience given improved understanding of community functions and priorities.

ENABLING INFORMATION ACCESS

Conclusion 4. Current policy and practices restrict access to information critical to public risk awareness, mitigation, preparedness, response, recovery, and community capacity for adaptation. Dam and levee safety processes and products (such as inspections, Emergency Action Plans [EAPs], and inundation maps) are intended to support decision making and enhanced community resilience, but are not readily available to all community members and stakeholders who make those decisions.

The availability of hazard- and risk-related data is essential for informed decision making on the part of dam and levee professionals and the broader community. Decisions or practices intended to support national security, protect proprietary interests, or minimize liability concerns, however, can also prevent dissemination of information critical to risk assessment and decision making related to safety and resilience. Dam and levee infrastructure could be managed better with greater understanding of upstream and downstream risk

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factors. For example, in the absence of accurate inundation maps, FEMA maps are often used to identify flood risks, but they do not depict the areal extent or the severity of floods that can result from dam or levee failure. Communities therefore cannot establish informed priorities or take informed action. Insurers and financial institutions make decisions without knowing potential catastrophic flood risks of any one location, or the potential aggregate effects. Common understanding of potential hazard scenarios, risks, and consequences is critical for the development of long-term sustainable solutions.

COLLABORATIVE RISK MANAGEMENT

Conclusion 5. Enhancing resilience will be most successful when dam and levee safety professionals and other community members and stakeholders identify and manage risk collaboratively in ways that increase understanding and communication of risks, shared needs, and opportunities.

Resilience-focused collaboration is a means of increasing understanding and communication of risks, shared needs, and opportunities if all elements of the community can be engaged and robustly vested in the outcomes of collaborative efforts. Social capital—the connections within community networks that can be used to meet societal objectives—is vital for community resilience. Resilient communities use their social and physical infrastructures and lifeline systems effectively to communicate and coordinate activities to mitigate, prepare for, respond to, recover from, and learn and adapt in response to disasters. Enhancing community resilience therefore implies greater interaction between dam and levee owners and the broader community than has been traditional in most dam and levee safety practices.

Collaborative identification of individual and collective issues, needs, resources, and solutions provides a means to manage systems, such as communities, that are too complex for any individual or entity to understand adequately. The benefits of collaborative engagement to dam and levee owners can include increased profitability and decreased liability (both as a result of reduced risk) and increased trust in and of the broader community. Regulators acquire a means to better promote public safety. Long-term benefits to dam and levee professionals come through the ability to contribute to and influence community planning and decision making (e.g., with respect to emergency management and recovery and land-use and financial planning).

Dam and levee safety programs, however, often operate independently of other community functions, and dam and levee professionals often fail to understand the value of community engagement and social capital to their own programs. Encouraging dam and levee professionals' participation in community resilience efforts will be most effective if the case is made from within the profession. Moving concepts of resilience into the mainstream

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of safety practice will take considerable effort on the part of professional associations and all agencies involved in dam and levee safety. Dam and levee professionals and the communities they serve need assistance identifying mechanisms for engagement in the form of tools, guidance, and examples of best practices, whether for the purpose of enhancing safety related to infrastructure operations, or for providing expertise, for example, in the management of land use, floodplains, or financial risk.

Conclusion 6. Risk-informed approaches allow dam and levee professionals to improve their understanding of infrastructure-system operations, performance, vulnerabilities, and the consequences of potential failures, and allow them and the broader community to make better decisions related to dam and levee infrastructure and resilience.

Risk-informed approaches are practices based on the information gathered through risk assessment and are not regularly applied in many dam and levee safety programs. Engineering design and operating procedures for dams and levees are primarily standards-based—for example, based on a defined level of infrastructure performance given a specific hazard. Standards-based approaches do not explicitly quantify performance uncertainty or risk. Risk-informed approaches, however, take into account the likelihood and consequences of different failure scenarios and can provide designers and operators more information with which to make technical decisions that improve safety. Communities also benefit from having information on the nature of potential failures, risks, and consequences. Resources can then be allocated more strategically based on the consequences for different community or stakeholder groups.

A CULTURAL SHIFT

Conclusion 7. Improving dam and levee safety programs to emphasize processes that enhance community resilience requires a culture shift among dam and levee professionals. This new emphasis requires embracing the responsibilities—and the benefits—associated with developing and implementing collaborative risk-management processes that facilitate enhanced community resilience.

A new norm for dam and levee safety practice requires overcoming institutional obstacles and establishing new goals that move practice beyond mere regulatory compliance. Dam and levee professionals will need to identify and engage community members and stakeholders, recognize shared goals and resources, and develop and implement processes that enhance community resilience. These include understanding factors critical for community well-being, creating more effective EAPs, being more aware of community land use

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and planning, and reducing liabilities as a result of reduced flood risk. This shift is more likely to be successful through incremental expansion of traditional dam and levee safety practices.

Whereas a cultural shift is necessary, the work to engage community members and stakeholders does not have to start from scratch. Models of collaborative engagement exist from which to draw, and dam and levee professionals already may have professional relationships with well-networked emergency-management professionals, local government and community leaders, local industry, chambers of commerce, and other community groups. Collaborative networks for enhancing community resilience may already exist in some communities for dam and levee professionals to join. Dam and levee professionals do not need to invent or lead collaborative efforts, but do have a responsibility to share their unique knowledge for their own benefit, the benefit of the organizations they represent, and the benefit of the larger community.

Figure S.1 is a conceptual framework for resilience-focused collaboration for the dam and levee safety community. Central to the framework are collaborative processes for resource and floodplain management including those for operational and risk communication, risk assessment, and preparedness and mitigation. Participation in, feedback from, and evaluation of collaborative processes by the community are necessary for effective and sustainable collaboration. Figure S.1 also illustrates that political, economic, cultural, physical environmental, and other community factors influence the effectiveness of collaboration, but may also be influenced as a result of collaborative efforts. Social capital, more informed decision making, and other resilience-related outcomes are among the benefits of collaboration that may lead to increased resilience.

BENCHMARKING PROGRESS IN SAFETY AND ENGAGEMENT

Conclusion 8. The federal government can aid resilience-enhancing efforts by identifying, cataloging, further developing, communicating, and facilitating the use of tools and guidance that already exist in the published literature and in federal and state guidelines. Many existing tools may need little or no modification to be useful for enhancing community resilience for specific situations. Cataloging existing tools is a first step in identifying and setting priorities for developing necessary new tools.

Integration of the ideas in this report into practice will be supported by the identification and selection of appropriate guidelines, methods, and means of selecting or implementing best practices for a given process. Examples of tools are dam inspection guidelines and floodplain zoning criteria. Because safety and resilience are community- and situation-specific, recommendation of the "best" tools is neither possible nor helpful. The federal

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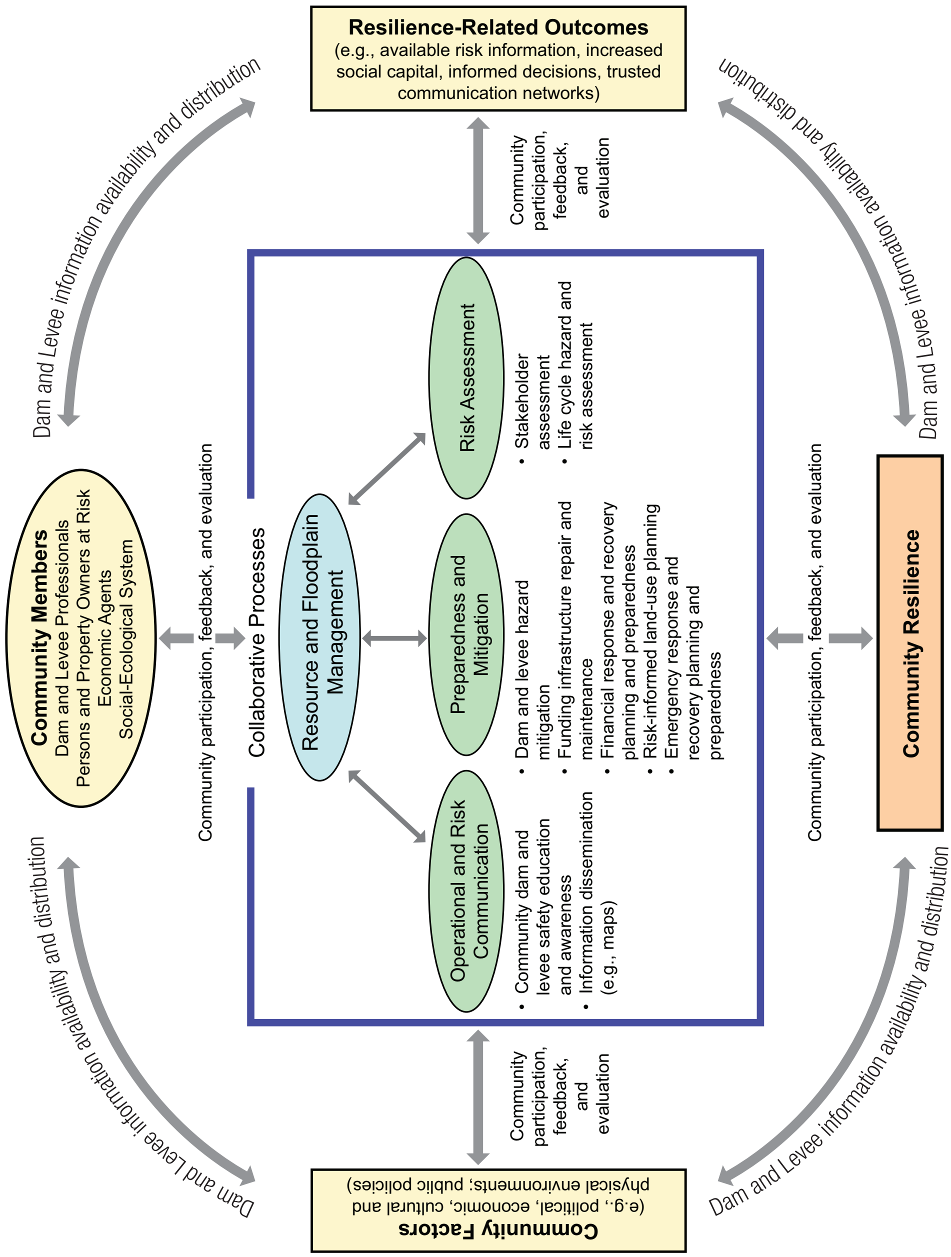

FIGURE S.1 Conceptual framework for resilience-focused collaboration related to dam and levee safety.

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government can best contribute to community-level resilience in a supportive role—through training and provision of information, guidance, tools, and appropriately considered best practices (all referred to as *tools* in this report). Because multiple federal agencies are involved in efforts to enhance community resilience, many tools may already exist and can be applied to safety and resilience efforts. Federal agencies with roles in dam and levee safety could review their own processes for enhancing safety and community resilience, and collaborate with states and representative owners to identify useful tools and resources, both existing and those that could be developed, that would most productively facilitate community-level resilience efforts. Cataloging and evaluating existing tools and best practices described in the published literature and elsewhere would result in a database that could be shared broadly.

Development of new tools is best informed through collaborative processes that take advantage of the expertise of key community members, stakeholders, and dam and levee professionals at all levels. Given the uniqueness of communities, tools and guidance are more useful if scalable, flexible, and able to provide the right level of analysis in different circumstances. One-size-fits-all tools, for example, may not be useful for both local- and state-level decision makers. The most effective means of making tools available at the community level need to be determined and acted on.

Attention by the federal government could be focused on the tools, training, and information that would help dam and levee professionals identify and engage community members and stakeholders; the community-specific processes for disseminating risk-related information; and identification of community priorities and resources. Also necessary is attention to improving risk-reduction and mitigation measures, land-use management, financial resilience and preparedness, and on the means to benchmark progress in all aspects of the larger effort to improve resource and floodplain management and community resilience.

Conclusion 9. Collaborative efforts that become a normal part of community functioning will enhance resilience more successfully in the long term. Continuous improvements in community resilience are more likely if such processes as community and stakeholder engagement assessment are institutionalized by dam and levee safety programs and the broader community.

Efforts to enhance safety and resilience can be sustained over the long term only with the widespread expectation that such efforts are necessary to improve community well-being. Formalized (e.g., institutionalized) programwide changes that expand current safety program goals of merely achieving regulatory compliance will need widespread acceptance. Community resilience cannot be created and sustained through short-term initiatives or activities of only a few in the community. Incremental steps that integrate activities of multiple community networks are required. Long-term plans that consider life-cycle benefits and costs of dam and levee infrastructure need to be widely communicated, understood,

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and acted on by the community in consideration of how actions fit into the larger resilience picture. Community engagement and the means of assessing and transforming engagement to inform long-term management of safety programs will make improving social capital, benchmarking processes, and identifying opportunities to improve community resilience part of the operational norm.

The greater community also needs to institutionalize engagement with dam and levee safety professionals into community functioning, perhaps as part of an already-existing all-inclusive community resilience strategy. An institutionalized forum for collaboration is needed in which community members, stakeholders, and dam and levee professionals can address community resilience issues, including resource and floodplain management; operational and risk communication; safety and resilience education and awareness; community member and stakeholder analyses; life-cycle hazard and risk assessment and mitigation; risk-informed land-use planning; funding for infrastructure repair and maintenance; financial preparedness, recovery, and response; and emergency response and recovery planning and preparedness. The mechanism for participation and feedback needs to be nonpartisan and not be tied to any particular administration or community-member bias.

Conclusion 10. Enhancing resilience requires frequent and collective evaluation of risk, safety, and collaborative processes. The proposed Maturity Matrix for Assessing Community Engagement can be used by dam and levee safety professionals, community members and stakeholders, and government entities at all levels to benchmark and manage the progress of industry and community processes related to safety and engagement. Details of assessment are necessarily unique for each community. The federal government can assist communities by providing an initial framework for the assessment tool, and providing information and training for its development and continued use at the community level.

Metrics for direct evaluation of community resilience, or the effectiveness of tools and processes to improve resilience, do not exist. The effectiveness of a tool or process depends in large part on its appropriate use given the abilities and collective goals of a community. The Maturity Matrix for Assessing Community Engagement (see Table S.1 for a generic example) can assist dam and levee professionals and the broader community in gauging the level of safety and resilience practice with respect to community engagement, and in improving understanding of how individual processes are parts of the larger resilience picture. The tool can allow communities to communicate operations already in place, identify weaknesses, decide on community resilience goals and priorities, and identify the means of meeting the goals.

The Maturity Matrix for Assessing Community Engagement is based on concepts developed in the software and systems engineering industry. It uses a matrix—called a

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TABLE S.1 Sample Entries for a Maturity Matrix for Assessing Community Engagement

Elements	Level I	Level II	Level III
Dam or levee safety reviews	No activity	Standards-based only	Introduction of additional review criteria (e.g., failure mode analysis)
Other programs related to conventional dam/levee safety activities	*Each tool is defined at different levels to show progression from minimum activity (Level I) through best industry practice to full community member and stakeholder engagement and collaboration (Level V)*		
Emergency action plans	No activity	EAPs developed internally by owner	EAPs developed with input from emergency management agency
Specific tools related to emergency planning response, including development of community preparedness measures, warning and evacuation procedures, and recovery plans	*Each tool is defined at different levels showing progression from minimum activity (Level I) through best industry practice to community member and full stakeholder engagement and collaboration (Level V)*		
Floodplain management	No floodplain management plans	Floodplain management plans in place	Floodplain management plans accommodate shadow floodplain associated with catastrophic dam or levee failure
Specific tools such as those related to land-use planning and floodplain management, including initiatives for financial incentives and zoning reform	*Each tool is defined at different levels showing progression from minimum activity (Level I) through best industry practice to community member and full stakeholder engagement and collaboration (Level V)*		

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Level IV	Level V	Examples of Possible Outcomes
Application of quantitative risk assessment by using criteria developed by owner or regulator with input from community members and stakeholders	Application of quantitative risk assessment by using criteria that reflect the community's societal values	Community is fully apprised of current level of risk
EAPs developed with input from community members and stakeholders and emergency management agency and shared with selected community representatives	Community collaboration with owners or operators to develop integrated EAPs that reflect community values	Community collaboration results in EAPs that minimize consequences of defined emergencies by incorporating community values and the potential for community resilience
Floodplain management plans integrated into community comprehensive or general plans	Floodplain management plans fully integrated into dam and levee owners' planning processes	Full participation by both community and dam and levee owners in floodplain management facilitates adoption of complementary resilience-enhancing measures

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maturity matrix—to assess how advanced or "mature" a program is with respect to a specific goal. A dam or levee safety program may create a maturity matrix with rows that describe specific program or community processes, such as dam or levee safety reviews, EAP development, floodplain management, and land-use planning. Columns under each maturity-level heading are populated with tools that are in place in the program or community for a specific function, and tools that should be in place at given increased levels of community engagement related to that function. The maturity levels represent a continuum of practice: from no activity or a small amount of structure-centric activity to fully informed community-centric processes that include incorporation of community priorities in decision making.

Maturity matrices are unique to each community and can be as complex as community needs dictate. It may be necessary to include several subheadings in any given row to address a specific goal fully. The community engagement process to create a maturity matrix is as useful as the developed matrix itself. Populating each cell of the matrix facilitates a complete assessment of a program's safety, communication, and engagement processes. Compiling the matrix compels dam and levee owners to scrutinize current goals and processes, helps them set goals for increased safety, engagement, and resilience, and to set priorities among goals. The exercise of developing the matrix is useful to bridge communication gaps among those who have different expertise, and the matrix itself is a vehicle for communicating with the broader community. Evaluating and choosing processes collaboratively helps generate a common vocabulary among community members and stakeholders.

Once developed, the matrix becomes a transparent mechanism for planning and evaluating community resilience. Regular self- and community assessment of safety and resilience programs using the matrix results in a visual reminder of status of the program or community with respect to specific goals. A community will never reach "100 percent maturity," because there is always opportunity for improvement or the need to respond to change. Similarly, maturity does not necessarily mean communities are free from risk. As the matrix is updated to reflect changing community or infrastructure conditions, it can be used to communicate where a program is more or less mature, and to prioritize community and program resource use to sustain and increase resilience, and to sustain the resilience-focused collaboration.

The assessment tool is scalable and readily modified for a large variety of resilience-related activities, programs, or types of infrastructure that affect resilience at different levels (local, state, regional, and national). Table S.1 is a generic matrix for dam and levee safety programs that, to be useful, must be customized by each community and each safety organization. The federal government can be instrumental in developing further the basic framework for the Maturity Matrix for Assessing Community Engagement and in developing guidance for its use.

To populate a community-specific matrix, safety programs and communities will need

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assistance determining characteristics of resilience in their communities, determining strategies for identifying and engaging community members and stakeholders, and determining the vulnerabilities and risks associated with all hazards and alternatives for reducing or mitigating them. Federal agencies that have responsibility for dams and levees can collaborate to examine safety programs, identify the means to improve their own knowledge of risk communication, advise communities how risk can be communicated in clear, understandable, and actionable terms, and to explore the role of community factors including legislation and land-use planning, in the severity of hazards and consequences to a community.

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CHAPTER ONE

Introduction

Dams and levees can create opportunities for development in previously flood-prone areas, but increased development in these same areas results in an increase in the number of people and livelihoods that depend on the safe functioning of dam and levee infrastructure. In one way or another, the roughly 84,000 dams (USACE, 2011a) and 100,000 miles of levees (NCLS, 2009) in the United States directly or indirectly affect most of this country's population. Although the presence of dams and levees may decrease the frequency of flooding, it can amplify the severity of flooding when it does occur (e.g., Burton et al., 1993; Pidgeon et al., 2003). The total number of fatalities associated with dam failures in the United States is less than the number associated with motor vehicles, bicycles, and commercial air travel, but a single dam failure has the potential to cause many hundreds or thousands of fatalities, to seriously affect services such as electric power, water supply, and irrigation, and to have major sociologic and psychologic effects, particularly when entire towns are involved.

In engineering terms, dams and levees fail when they do not deliver the services for which they are designed, such as flood protection, water supply, and hydropower. This report defines *failure* from a community member's point of view; the infrastructure "failed" to protect the community from flooding. Therefore *failure* refers to flooding caused by any uncontrolled or controlled flow of water that threatens lives, property, or livelihoods. Modes of failure that result in flooding include overtopping, breaching, structural collapse, leakage, damage to or failure of hydraulic control systems (e.g., gates and valves), misoperation, and operational decisions that intentionally keep water levels high (in which case floods may result from controlled flow). The committee adopts this definition because community resilience, as described in this report, depends on understanding and acting against potential and actual flood consequences, regardless of whether dams and levees functioned as designed.

Direct effects of dam and levee failure are threats to health, safety, and property associated with inundation. Indirect physical effects include adverse effects on drinking-water

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supplies, power generation and transmission, communication systems, transportation systems, agricultural resources, and sanitation. Social effects can include psychosocial impacts (e.g., depression), demographic impacts (e.g., in- and outmigration), economic impacts (e.g., business disruption), and political impacts (e.g., mobilization of emergent groups) (Lindell et al., 2006). Such social effects can cause major disturbances on the social and organizational networks that are the core of much of community functioning. Other effects on the proximate community are to be expected. Indirect effects, however, can expand well beyond the local area. The financial effect of flooding, for example, may be national or global as a result of interruptions to commercial supply chains or financial markets (e.g., see A.M. Best, 2012). Failure can cause widespread disruption of normal societal functioning and affect communities, commerce, and individuals.

Because the effects of dam or levee failure on physical and social infrastructures can be broad, a more comprehensive approach to dam and levee safety beyond traditional standards-based and structurally based safety goals is needed. The earthquake-engineering profession has learned through experience that engaging a community in hazard preparedness, risk communication programs, response and recovery planning and training, and formulation of new adaptations can pay large dividends in reducing the short-term and long-term effects of an event (e.g., NRC, 2011b). For example, property damage in the 1994 Northridge, California, earthquake was lower in communities that had stronger hazard mitigation plans and stronger code enforcement efforts than in communities that did not (Burby et al., 1998).

Similar outcomes may be expected as a result of safety and resilience initiatives associated with dams and levees, although the committee recognizes that plans implemented for each type of infrastructure will necessarily be different. Communication and collaboration among all affected before, during, and after a failure—including communication related to flood risks, anticipating and planning for likely events, evacuation planning, and warning—is essential if planning is to make mitigation, preparedness, response and recovery operations, and other long-term adaptations timely and successful. The Federal Emergency Management Agency (FEMA) requested the present study to aid in development of initiatives to help decision makers reduce risk to life and property caused by dam or levee failure—initiatives that take resilience of the community fully into account.

THE COMMITTEE'S TASK

Under the sponsorship of FEMA, the National Research Council convened a panel of experts to consider how dam and levee safety as a concept and a practice can be expanded to promote the core values of FEMA's mission—to improve community, regional, and national resilience. The committee includes researchers and practitioners who have expertise in dam and levee safety engineering, hydraulic engineering, risk reduction, disaster

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management, and human response to risk. It also includes members who have expertise in critical-infrastructure protection; risk analysis, communication, and perception; quality assurance and compliance; economics; risk management and insurance; urban planning; and floodplain management. Appendix A presents brief biographies of the committee members. The committee's statement of task from FEMA appears in Box 1.1.

This report communicates concepts of community resilience and describes the roles dam and levee professionals can serve with other community members in increasing community resilience with respect to dam and levee failure. The committee identifies efforts

BOX 1.1
Statement of Task

An ad hoc committee of the National Research Council will analyze and provide conclusions on how dam and levee safety programs may be broadened to include community- and regional-level preparation, response, mitigation, and recovery from potential infrastructure failure. The study will examine

- Holistic systematic approaches to safety analysis. Links between the geotechnical, geologic, hydrologic and hydraulic, and civil-structural engineering aspects of safety and the risks to communities and other stakeholders will be identified. The committee will consider how incorporating mitigation, preparedness, response, and recovery into safety programs can enhance long-term community- and regional-level resilience.
- Communication and engagement. The committee will describe current practices for identifying local and regional stakeholders, and for collecting and disseminating information among them, including how concerns are reassessed as infrastructure conditions change, safety issues emerge, and community needs and interests evolve. Conclusions regarding the improvement of these practices will be provided.
- Decision-making and decision-support systems. The committee will summarize how safety information, including stakeholder input, and inspection, monitoring, analysis, and impacts data are used in safety programs for decision making for both infrastructure management and improving community- and regional-level resilience against the primary (e.g., inundation) and secondary impacts (e.g., regional power loss) of infrastructure failure. The committee will provide conclusions regarding how stakeholder input may be incorporated into the design of safety and communication decision processes.

The committee will identify tools, products, and guidance that could be developed at the federal level to address the issues above. The human behavioral drivers that may promote or inhibit the expansion of dam and levee safety programs to promote community resilience will be considered. The committee's conclusions will assist the federal government in developing a more comprehensive and effective dam and levee safety program, but no policy or funding recommendations will be made.

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that can be undertaken to enhance community resilience in the face of possible unexpected and adverse performance of dams and levees. The committee's assessment is necessarily at a very high level, given the range of issues faced by individual communities as they deal with different infrastructure types, hazards, and risks. The committee presents a framework for incorporating resilience into dam and levee safety programs that can be applied by dam and levee owners at all levels, and by the broader community. Through the use of such a framework, safety programs and communities can individualize the steps necessary to promote resilience in their own communities. Those who will benefit from the proposed framework include dam safety professionals (e.g., owners, operators, and regulators), emergency management agencies, and the broad array of others, including persons and property owners at direct risk, members of the wider economy, and institutions and organizations involved in governance, communication, mass media, social support, and environmental and cultural management.

HISTORICAL DAM AND LEVEE PERFORMANCE

Dam and levee governance is a key factor in dam and levee safety. Much progress has been made, at least in the governance of dams, since the late 1970s and the establishment of the National Dam Safety Program (see Chapter 3 for discussion of dam and levee infrastructure, management, and governance). Review of the historical record of dam failures can yield information regarding failure likelihood and effects. Engineers and professional organizations have documented dam failure in an ad hoc manner for decades (e.g., Black, 1925; Middlebrooks, 1952; Babb and Mermel, 1968; ASCE/USCOLD, 1975, 1988). Failure-mode documentation is more commonly aimed at improving understanding of infrastructure failure and typically does not include consideration of failure consequences (Hoyt and Langbein, 1955; Ellingwood et al., 1993). Economic consequences, which can be considerable, are seldom considered (Ellingwood et al., 1993), and social, environmental, and other costs are rarely identified.

The committee was unable to identify a comprehensive list of levee failures and resulting consequences in the United States, but it did find a list of levee failures in the Sacramento–San Joaquin Delta area in California (USGS, 2000; Gaddie et al., 2007). Compilation of a list of historical levee failures would likely yield important information regarding hazards and risks associated with levees.

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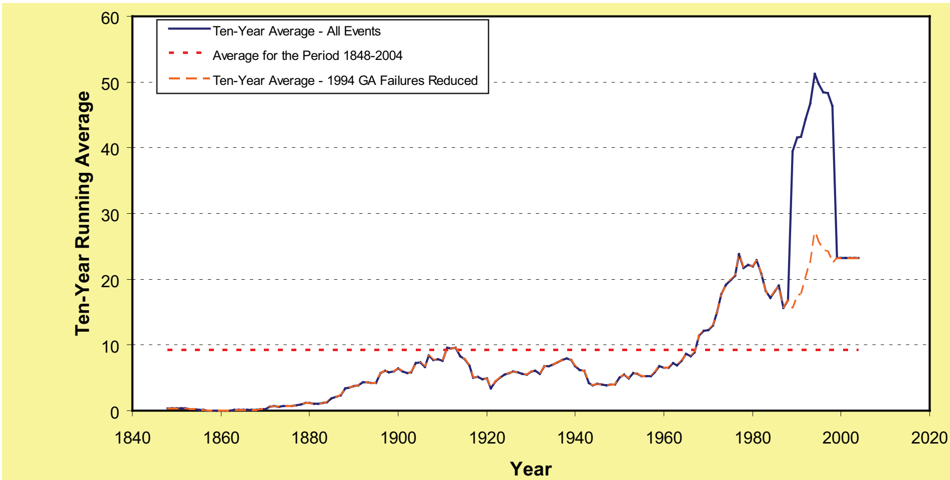

FIGURE 1.1 Average number of dam failures over the period of record and 10-year running averages of dam failures in the United States since 1850.
NOTE: The red dashed line represents the result with failures from the 1994 extreme floods in southern Georgia excluded.
SOURCE: NPDP (2007). Reprinted with permission; copyright 2012, Stanford University.

Dam Failures

Nearly 1,500 dam failures have been recorded in the United States since the middle of the 19th century.[1] Figure 1.1 shows a running 10-year average of the dam failure rate and long-term (period of record) dam failure rates since 1850. The figure represents dams of all sizes and types, including small dams, whose failures have little or no consequences.[2] The long-term average rate of dam failures is about 10 per year. The increase in failure rates beginning in about 1970 probably correlates with the increase in the number of dams built in the latter half of the 20th century combined with the increased reporting of dam failures after the 1972 Buffalo Creek and 1976 Teton Dam failures. Many failures are associated with dam spillways designed to discharge the estimated 50-year or 100-year peak flood flow rate, and many small dams are not designed with adequate spillway capacities to handle a 100-year-flood event. Many of those dams can be expected to fail at some point in their operation. Figure 1.2 shows the long-term average and 10-year running average of fatalities on record as a result of dam failures in the United States.

[1]There is no way to know the accuracy of the historical record of dam failures in the United States.

[2]See Stamey (1996), for information about the effects of Tropical Storm Alberto in 1994 on flooding, especially the failures from extreme floods in southern Georgia excluded from Figure 1.1.

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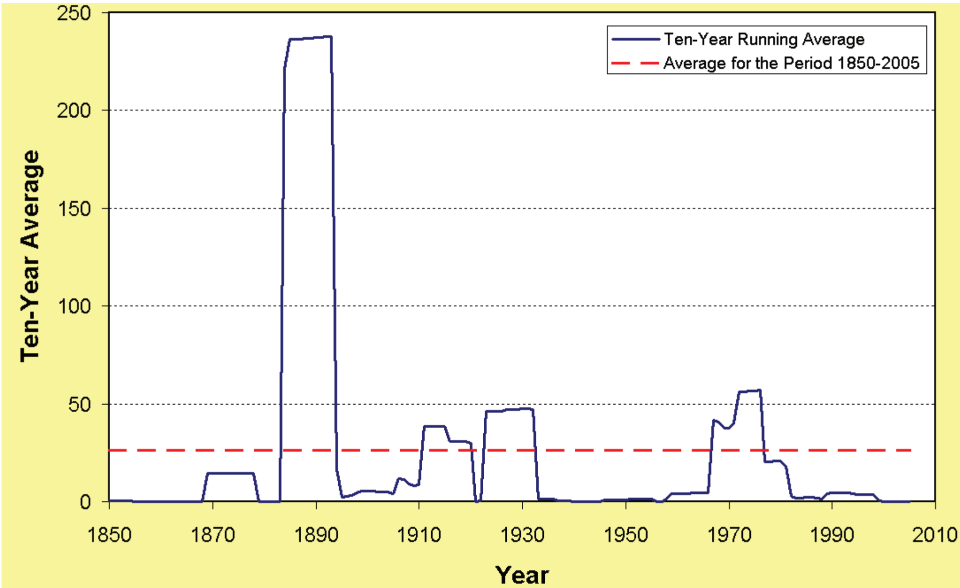

FIGURE 1.2 Ten-year running average (blue line) and average reported fatalities due to dam failure in the United States. SOURCE: NPDP (2007). Reprinted with permission; copyright 2012, Stanford University.

Consequences of individual dam failures have been substantial. For example, the failure of the South Fork Dam in Johnstown, Pennsylvania, in 1889 resulted in 2,209 fatalities (Graham, 1999). Table 1.1 is a partial list of major dam failures in the United States and their consequences. Since the middle of the 19th century, over 4,000 fatalities have been associated with dam failures; over half resulted from the South Fork Dam failure in Johnstown, Pennsylvania.[3]

Levee Failures

A comprehensive list of levee failures in the United States is not readily accessible. However, the Sacramento–San Joaquin Delta, with about 1,100 miles of levee, has experienced approximately 160 levee failures in the last 110 years (Gaddie et al., 2007). The 1993 and 2011 flooding in the Midwest also caused multiple levee failures or prompted intentional breaches[4] (Larson, 1996). The most costly levee failures in the United States

[3]It is not known whether all the fatalities are attributable to the dam failure or if some occurred as a result of natural flooding that caused the dam failure.

[4]For example, see water.usgs.gov/osw/floods/2011_BPNM/ (accessed March 1, 2012) for information and resources related to the 2011 intentional breach of the Birds Point–New Madrid Floodway.

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TABLE 1.1 Selected Major Dam Failures in the United States

Date	Dam Location	Consequences of Dam Failure
May 16, 1864	Williamsburg Dam Williamsburg, Massachusetts	Flooding from the Mill River resulted in 139 fatalities, left 740 homeless, and destroyed several factories (Sharpe, 2004).
May 31, 1889	South Fork Dam Johnstown, Pennsylvania	Overtopping resulted in 2,209 fatalities and an estimated $17 million (1889 dollars) in property damage in Johnstown (McCullough, 1987; see also JAHA, 2012).
June 29, 1925	Sheffield Dam Near Santa Barbara, California	Dam failure resulted from liquefaction induced by the Santa Barbara earthquake; no fatalities were reported (Seed et al., 1970).
March 12, 1928	St. Francis Dam Santa Clarita, California	More than 450 people died, and the city of Los Angeles paid $7 million (1929 dollars) in restitution to families. Failure of the dam focused public scrutiny on the safety of dams in the United States (Rogers, 2006).
February 26, 1972	Buffalo Creek, West Virginia	Failure of a mine tailings embankment resulted in 125 fatalities, 1,121 injuries, over 4,000 left homeless, over 500 homes destroyed, and property and highway damage estimated in excess of $65 million (WV Ad Hoc Commission of Inquiry, 1973; Erikson, 1978). Public attention to the hazards created by water reservoirs after the disaster led to the enactment of the National Dam Inspection Act (Public Law 92-367).
June 5, 1976	Teton Dam Near Rexburg, Idaho	Failure of a U.S. Bureau of Reclamation dam due to internal erosion resulted in 11 fatalities and over $1 billion dollars in property damages. The failure led to widespread review by federal agencies regarding dam inspection, evaluation, and modification. The federal government paid 7,563 claims ($322 million) (USBR, 2011b).

continued

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TABLE 1.1 Continued

Date	Dam Location	Consequences of Dam Failure
November 6, 1977	Kelly Barnes Lake Dam Taccoa, Georgia	Floods from the dam failure resulted in 39 fatalities and $2.8 million in damages (1978 dollars) (Sanders and Sauer, 1979).
March 14, 2006	Kaloko Reservoir Kauai, Hawaii	The flood destroyed homes, damaged a highway, and resulted in seven deaths (Godbey, 2007).

occurred as a result of Hurricane Katrina in 2005 (Knabb et al., 2005), which resulted in substantial loss of life and social-ecological and economic impacts in New Orleans. Hurricane Katrina prompted a modern recognition of the potential scale of effects of levee failure in populated areas. Table 1.2 is a partial list of floods and consequences in the United States caused by levee failure or overtopping.

BASIC CONCEPTS IN THIS REPORT

Hazard and *risk* are terms that are sometimes used carelessly (and often interchangeably) in the technical literature of many fields of expertise. In this report, *hazard* refers to the potential to cause harm. Flooding from dam or levee infrastructure, for example, is a hazard. *Risk* is the combination of the likelihood a hazard will occur, and consequences of the hazard, should it occur. The probability and consequences of flooding are risks of flooding. Currently, dam and levee safety focuses on geotechnical, geologic, hydrologic, hydraulic, and structural factors that are critical in the performance of dam and levee infrastructure. Dam and levee safety also currently focuses on the control of hazards rather than control of risk. From the perspective of dam and levee safety professionals, the basis of many safety issues is literally and figuratively grounded in the engineering design of the critical infrastructure. For example, geotechnical issues were at the root of floodwall failures in New Orleans during Hurricane Katrina (IPET, 2007a) and remain a systemic problem for many embankment structures. Geologic and hydrologic properties are the driving forces of many dam-safety issues, including the persistent foundation issues of the Wolf Creek Dam on the Cumberland River in Kentucky (see Box 1.2) and increased inflow hydrographs for reservoirs in the Sierra Nevada Mountains due to early snowmelt and runoff (e.g., Cayan et al., 1997). Hydraulic issues were paramount in fighting the epic Mississippi River flood of 2011 when unprecedented volumes of water needed to be managed to prevent wide-

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TABLE 1.2 Selected Major Flood Events Involving Levees

Date	Location	Description
April–October 1993	Midwest region	Flooding resulted in 50 fatalities, $15.6 billion in damages, breaching or overtopping of 40 of 229 federal levees, and breaching or overtopping of 1,043 of 1,347 nonfederal levees (Larson, 1996; NCLS, 2009).
January 1997	Northern California	Flooding in the Sacramento and San Joaquin river basins forced 120,000 people to evacuate and caused about $2 billion in damages, including over $1 billion in damages of public infrastructure (FEAT, 1997).
August–September 2005	New Orleans, Louisiana	Storm surge produced by Hurricane Katrina caused 50 levee or floodwall failures throughout New Orleans (Sills et al., 2008), flooding, and evacuation of over 800,000 residents (Wolshon, 2006). Flooding caused over 1,600 fatalities, about $26 billion in insured property losses, and over $100 billion in total losses (Knabb et al., 2005).
June–July 2008	Midwest region	Flooding resulted in 11 fatalities and an estimated $2 billion in property loss; about $2.7 billion in federal disaster relief was approved in 2009 (NCLS, 2009).
May–June 2011	Midwest region	Floods caused no direct fatalities or breaches in federal levees. The U.S. Army Corps of Engineers induced breaching to activate floodways to reduce pressure on mainline river levees below St. Louis.

spread losses.[5] Such issues affect dam and levee structures for which the ability to forecast performance is often (especially for levees) limited by lack of information concerning their condition and reliability. Such issues directly contribute to hazards and risks faced by associated communities that may not have full understanding of the extent of risk.

[5]See www.mvn.usace.army.mil/bcarre/floodfight.asp.(accessed March 1, 2012).

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BOX 1.2
Wolf Creek Dam, Kentucky

The Wolf Creek Dam (Figure 1) in south central Kentucky was built as part of the development of the Cumberland River Basin. The dam serves multiple purposes in the region: it provides flood control, stores water, is a source of hydro-electric power production, allows navigation on the river, and is a major source of recreation in the area. A U.S. highway was built on top of the dam. Construction of the rolled-earth fill and concrete gravity structure began in the 1940s and was completed in 1952. In the late 1960s, muddy waters were noted near the dam, and two sinkholes developed at the toe of the embankment (Figure 2). Studies indicated an extensive and intercon-nected network of solution channels in the limestone beneath the dam. Grouting was done as an emergency measure, and in the late 1970s, a diaphragm wall was constructed through the earth embankment into the limestone foundation to block seepage.

FIGURE 1 Wolf Creek Dam on the Cumberland River in Kentucky. SOURCE: USACE, Nashville District, 2011.

The dam continues to have seepage problems and is considered to be at high risk of failure. The U.S. Army Corps of Engineers (USACE) estimates potential loss of over $3 billion in property dam-ages in the event of sudden failure. USACE is taking emergency measures to prevent imminent failure, including lowering of reservoir levels, but the lowered reservoir levels significantly affect local communities. A new, deeper, and longer concrete diaphragm wall is being constructed at a cost of over $340 million to address the continuing seepage problem. Construction is expected to take 4 years to complete.

FIGURE 2 One of two sinkholes that appeared in the embank-ment of Wolf Creek Dam in 1968. SOURCE: USACE, Nashville District, 2011.

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Being able to define hazards from all sources, understand the reliability and expected performance of dam and levee infrastructure, know the risk (potential for losses) associated with those hazards, and take measures that are necessary to reduce the risk to a point where a community can avoid, minimize, or recover from an undesirable event requires an evolution of focus beyond current concepts and practice of safety. A holistic and systematic approach on the part of dam and levee professionals and associated communities is required. Programs that take such an approach begin by assessing the geologic, geotechnical, hydrologic, and hydraulic processes and factors and their influence on the reliability and performance of dams and levees—all of which are fundamental to dam and levee safety with respect to the design and operation of infrastructure. Programs take the approach further by communicating hazards, the potential for failure events, and early warnings to communities and stakeholders. Programs go further still by working with communities to decide on appropriate risk-reduction measures. However, there are fundamental barriers to translating expertise and analyses of data to risk assessments and community emergency management that enable community risk reduction. For one, national guidelines and standards for dam safety are not well developed and hardly exist for levee programs. Another barrier is that dam and levee safety programs do not generally quantify risk and uncertainty explicitly in their design and operation of geologic, geotechnical, hydrologic, and hydraulic processes that can inform both themselves and associated communities.

In light of such barriers, the uniqueness of safety engineering issues related to specific dams and levees, and the uniqueness with which communities manifest resilience, this report focuses on dam and levee safety practices in general terms. Many challenges that dam and levee professionals face with respect to enhancing resilience are similar regardless of the professionals' individual technical expertise. This report provides general fundamental perspectives for a holistic approach to dam and levee safety analysis and operation that can improve decision making for program and community management of risk. Given an understanding of the approach, the ideas can be tailored to individual safety programs and customized further to suit the needs of particular safety-program components.

The following sections define key terms used throughout this report. Many of these terms are used differently in different disciplines (e.g., engineering and the social sciences), and many of the terms in this report are used in a slightly different manner from those traditionally used in engineering. The committee has made efforts to use definitions consistent with those of FEMA.

Resilience

Resilience is often defined in the engineering, physical science, and ecological communities as the ability to recover from stress. *Robustness* is often defined as the ability to withstand stress without loss of function. Past National Research Council committees

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(e.g., NRC, 2011a) have adopted broader definitions of resilience derived from Berkes and Folke (1998), Gunderson and Holling (2002), and Norris et al. (2008), who described it as the ability to prepare and plan for, recover from, or successfully adapt to adverse events. Walker and Salt (2006, p. 113) have defined it as "the capacity of a system to absorb change and disturbances, and still retain its basic structure and function—its identity."The latter definition combines the engineering concepts of resilience and robustness and is consistent with FEMA's use of the word. To be consistent with FEMA, the present committee has adopted the Walker and Salt definition.

Given this definition of resilience, it is important to understand that recovery from an adverse event does not necessarily involve a community's returning to pre-event conditions. Healthy communities are not static, and resilient communities are the ones able to adapt to changing conditions so they can continue to function (Norris et al., 2008). Recovery from and adaptations made as a result of a flood or other adverse event can lead to a community that is different, and perhaps improved, from the one that existed before. Because resilience is dynamic, it requires continuing managerial and social change among the individuals, networks, and institutions that make up a community.

Hazard Mitigation and Adaptation

Resilience is ultimately demonstrated by the ability to anticipate hazard events, survive the disruptions that they cause, mount effective responses, recover from the effects of infrastructure failure, and change behaviors to mitigate and prepare for future events. It can be increased by the ability to predict the nature of potential failures, stresses, and consequences and with collective action to mitigate, prepare for, respond to, and recover from failures that occur. Resilience also implies readiness to respond to and recover from unanticipated events. Learning and adapting as a result of failure increases resilience and allows better preparation for future events.

The committee uses the term *hazard mitigation* to include the variety of actions taken by the private and public sectors to reduce vulnerability, to ease recovery from any losses that are experienced, and to plan for future events. Hazard-mitigation activities include developing and implementing infrastructure design standards and practices, land-use planning, regulation development and enforcement, the buildup of community awareness and knowledge, acquisition of appropriate flood insurance, and strengthening of institutions and communications. Post-disaster recovery planning can minimize hazards caused by the disaster, or minimize hazards that may emerge in the turbulent period following a disaster. From that perspective, activities that some consider part of recovery preparedness may also be mitigative. Hazard mitigation is much broader than what is sometimes termed structural hazard mitigation or hazard control—actions of dam and levee owners to improve resilience

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through infrastructure design and operation. Mitigation measures can lead to community resilience with adequate capacities for preparedness, response, and recovery.

Adaptation refers to adjustments to a new or changing environment that take advantage of beneficial opportunities or moderates negative effects (NRC, 2010a). Adaptation often involves behavioral or institutional changes and can occur during mitigation, preparedness, contingency planning, and response and recovery operations. Communities adapt by reducing their vulnerability to emerging or future hazards that could become seriously disruptive if left unaddressed. Dam and levee failures and their consequences have traditionally been dealt with in the natural-hazards literature. Risk analysis in the broadest possible definition, however, is now the dominant analytic framework in the federal government, in major corporations, and internationally. The dam and levee safety community is beginning to take a more risk-informed approach in its activities.

Vulnerability and Risk Management

Vulnerabilities are characteristics and circumstances that make a community, system, or asset susceptible to the damaging effects of a hazard (UNISDR, 2009). Risk is a function of both the characteristics (consequences) and the likelihood (probability) of a potentially harmful event and the vulnerabilities of a community subject to that harm. Few policies or standards applicable for the majority of dams and levees are in place to direct practice with respect to the consequences and probabilities of harmful events, and with addressing vulnerabilities. Management of risk is possible if risks and uncertainties related to hazards are understood. Risk-based management approaches use risk as a metric to determine compliance with agreed-upon safety objectives to inform decision making. At times, however, risk or uncertainty cannot be completely quantified, or there are no standards to serve as a basis for decision making. Under such circumstances, knowledge of risk (e.g., available quantitative and qualitative information) allows *risk-informed* management. Risk information becomes input to decision making.

Reliability

Reliability is generally defined as the likelihood a system will not fail at any particular time (e.g., Hashimoto et al., 1982a,b). In this report, however, the notion of reliability is extended to incorporate not just the likelihood of a specific harmful event but the uncertainty in determining the likelihood. It also includes the performance of measures taken to reduce vulnerability.

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Community

The committee defines *community* as individuals, groups, and institutions in the immediate geographic area of a dam or levee and all individuals, groups, and institutions that benefit from or experience the loss of services as a result of the direct or indirect effects of (in this case) flooding—whether in the geographic area or not. A National Research Council study on characterizing risk defined *stakeholders* as all interested and affected parties (NRC, 1996). Potentially affected parties are not always aware of—and perhaps not interested in—their exposure to risk.

The committee recognizes two facets of *community*. The proximate community is the community near dams and levees where failure threatens loss of life and property, and where community identity is connected to a geographic location. The broader community experiences the "ripple effects" of floods and typically exists in networks that extend beyond the proximate community. It includes all stakeholders who benefit from the continued safe functioning of the infrastructure in question, whether or not they recognize their stake. All stakeholders can be considered members of this broader community. To distinguish between the proximal and broader communities, the committee uses the term "community members" when referring to those in a geographic or jurisdictional region at risk of flooding, and "stakeholders" to refer to those outside of that region.

Communities are resilient if they learn from adversity and modify their social and physical infrastructure and lifeline systems to withstand major shock without long-term debilitating damage (e.g., Godschalk, 2003) and anticipate hazard events.

COMMITTEE REFLECTIONS ON ITS TASK

The statement of task charges the committee with determining how safety program objectives could evolve into those that include enhancing community resilience. It does not charge the committee to assess "safety," or specific technical issues related to safety. Part of the evolution includes a greater emphasis on systems analysis—identifying the interactions and interdependencies of the infrastructure–river–reservoir–community system elements.

Stephen Verigin, vice president and a chief geotechnical engineer of GEI Consultants (and former chief of the California Department of Water Resources Division of Safety of Dams), stated a major paradigm shift would be necessary to move the nation's dam and levee safety programs toward a culture of resilience.[6] In his opinion, such a shift would include new authorizing legislation, changes in management, a reorientation from deterministic to risk-based approaches, and engagement and support from a much larger community, including local government, planning agencies, elected officials, and the public. He advo-

[6]S. Verigin, GEI Consultants, Presentation to the Committee, March 10, 2011.

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cated for statutory definitions and broadening of dam safety programs that would include well-documented risk-based design criteria, disciplined land-use and zoning activities, flood control requirements set in law, and integrated flood control systems that include highly protected areas, planned floodways, and flood easements. Commitment on the part of agencies participating in the control of hazards and risks would be necessary, as would common understanding of roles and responsibilities among dam and levee safety professionals, local government, planning agencies, elected officials, and the public.

The committee endorses the sentiments of Mr. Verigin's assessment, but before the committee could develop the elements of a framework for such changes, the committee established two underlying principles as the foundation of its discussion. The first principle is that although the likelihood of adverse performance of dams and levees can usually be reduced, failures will occur. The second principle is that communities can prepare for and reduce the consequences of failure and can institute adaptations through collective and collaborative efforts (based on mutual appreciation of hazards and consequences) to enhance community resilience. The next sections summarize the committee's other starting assumptions and method of analysis.

Underappreciated and Undervalued Infrastructure

The nation as a whole may not appreciate the value of dam and levee infrastructure, the long-term life-cycle costs associated with built infrastructure, or the concerns of local community members. Maintenance and ultimate replacement costs need to be factored into life-cycle accounting for infrastructure, as do costs associated with enhancing resilience of communities that are placed at risk. Potential consequences need to be understood and values placed on them. Competing priorities often force community resilience to take a back seat to issues that seem more immediate. Maintenance is also postponed, sometimes indefinitely. Burby (2006) describes paradoxes that explain some losses caused by the failures due to Hurricane Katrina in 2005—that governments may actually increase the potential for catastrophic consequences in trying to make hazardous areas safer in the short term. Communities and their citizens ultimately suffer and bear financial loss because of land development practices that do not take into account the limitations of flood protection measures.

Physical and Social Infrastructure and Resilience

Dams and levees serve different functions in the control of surface water, but regardless of initial intent in design, they are components of surface-water systems. Infrastructure decisions made for one part of a river system are likely to affect other parts of the system. The resilience of the entire system depends on the robustness of physical and social infrastructure, on decisions made about infrastructure use and operations, on preparation for

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and response to events, and on understanding the effects of decisions and how protective actions can be mounted. There is a reciprocal relationship between land use and dam and levee infrastructure design and operations. Efforts to enhance community resilience are hampered without an understanding of how the physical and social assets and services derived from the infrastructure are, or are not, resilient to disasters, although the connection between infrastructure resilience models and community resilience is not well understood (Miles, 2011).

Community resilience as related to dam and levee failure is built on a robust physical and social infrastructure. Components must be designed and maintained according to a set of specifications that are intended to limit the chance of failure and its effects over a given period. Given changes in land use, for example, levees built to protect agricultural lands are now expected to protect heavily populated areas. Attention is increasingly turning to the need for higher standards in design and construction when urban populations can be exposed to deep flooding. This report describes, in general terms, current dam and levee safety practices for ensuring robustness of infrastructure systems, how these practices might be improved, and how they might be extended to include a more holistic approach to improving the resilience of the community to a variety of foreseeable flood events.

Community Preparedness and Mitigation

A more holistic approach requires more communication among infrastructure safety engineers, owners, managers, and key community members and stakeholders—a continuing discussion that emphasizes risk and consequence communication and planning to avoid, mitigate, or adapt to the hazards associated with dam and levee failure. Dam and levee owners' and (in the case of dams) regulators' incomplete understanding of hazards, of potential failure scenarios, and of the short-term and long-term consequences for the entire community leads to increased risk for the community as a whole. Appropriate actions by dam and levee professionals and the broader community are necessary to prepare for and reduce physical and financial risks to public and private property and thus to protect, for example, the social, government, and economic dynamics that are the underpinnings of a resilient community.

Hazard mitigation requires close collaboration between dam and levee owners and the communities, both proximate and more broadly, that face risks from infrastructure failure. Effective collaboration extends beyond the provision of data by dam and levee owners on the degree of risk faced by communities and may include, for example, dam and levee owners acting as champions of community hazard mitigation and convening meetings of community members and stakeholders to discuss the serious nature of risk and the mitigation actions that are appropriate. Those and other examples are provided in Chapters 4 and 5 of this report. The interrelationships between infrastructure operators, the private and public

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sectors, and individual citizens in decision-making processes that could increase community resilience are discussed throughout this report.

Tools for Improvement

The committee's statement of task directs the committee to "identify tools, products, and guidance that could be developed at the federal level" to assist dam and levee safety programs in addressing holistic systematic approaches to safety analysis, communication and engagement, and decision-making and decision-support systems to support community resilience. This report defines tools as the guidelines, methods, and means of selecting or implementing best practices for a given process. Tools include products designed to accomplish specific tasks, and frameworks for general program organization. The committee provides a high-level assessment of what tools would facilitate action but does not conclude specifically what those actions should be.

Although tools, standards, and policies to improve infrastructure design and safety are important and necessary, the committee's task does not include assessing those. Instead, the committee considers tools to assist individual safety programs (those responsible for the safe operation of individual dams and levees) in identifying the communities and stakeholders affected by the consequences of dam- and levee-related technical decisions. The committee also explores tools to improve two-way communication of information that can help communities become more resilient and provide additional information to safety programs that may guide technical decisions.

Methods

Given the above assumptions, the committee set about accomplishing its task through

1. Gathering data. During open sessions of its meetings, the committee heard presentations from and had discussions with multiple individuals representing different sectors within the dam and levee industry (see open session meeting agendas in Appendix B). Individual committee members conducted interviewers with other relevant professionals, requested and examined statistics from the USACE National Inventory of Dams,[7] and collected an extensive amount of information on a variety of dam and levee safety topics including regulations, guidance, standards, historical dam and levee performance, and current safety practices. The committee

[7]See geo.usace.army.mil/pgis/f?p=397:1:0. The committee was not given access to the full inventory, but received statistical information about dam type, height, storage, and hazard classification without reference to location.

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also explored the literature in several disciplines, including and especially literature related to resilience.

2. Identifying practices, gaps, and challenges in current safety practice. The committee considered how current safety practices contribute to community resilience, and in what ways such practices could be improved.
3. Identifying frameworks for resilience building. The committee identified an appropriate model for a resilience framework that could be applied to dam and levee safety programs. The committee particularly focused on the work of the NRC Committee on Private-Public Sector Collaboration to Enhance Community Disaster Resilience tasked with recommending a structure that could enhance private-public collaboration with the objective of increasing community resilience (NRC, 2011a).
4. Developing a vision. The committee considered the potential of dam and levee safety programs for contributing to community and national resilience, and created a new dam- and levee-specific framework for resilience-focused community engagement, and the assessment of that engagement.
5. Considering the role of the federal government in promoting and facilitating resilience-focused activities.

REPORT ORGANIZATION

This report addresses how to incorporate concepts of community resilience into dam and levee safety programs and practice. Much of the report is written for dam and levee safety professionals, but the discussion is general and of use to the broader community interested in becoming more resilient. Some background on dam and levee safety practices is provided for those not as familiar. Chapter 2 expands on the definition of community already provided and describes characteristics of resilient communities. Chapter 3 provides a general description of current dam and levee infrastructure, its management, and its governance. Chapter 4 provides the committee's vision for future management of dam and levee infrastructure. It includes a framework for collaboration with the broader community that is necessary to enhance community resilience. Chapter 5 describes what would be necessary to make that vision a reality and provides the basis of assessing the progress of processes put into place to enhance resilience. Tools and guidance that could be provided at that federal level are also included. Chapter 6 reiterates the committee's major conclusions related to the cultural shifts necessary to improve dam and levee safety practice to promote community resilience.

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CHAPTER TWO

Community Characteristics and Improving Community Resilience

Chapter 1 briefly describes the dam and levee community as the individuals, groups, and institutions affected by the physical impacts of inundation, as well as those that experience indirect consequences such as financial burden or loss of public services. A community includes but is not limited to those who live or work near dam or levee infrastructure (e.g., in a floodplain). Major floods can affect investors and financial institutions, commercial risk managers, the insurance market, and organizations such as the Federal Emergency Management Agency (FEMA) itself, that operate far from the infrastructure or flooding. Community members and other stakeholders are those who bear flood-related risk and can benefit from increased resilience.

FEMA's National Disaster Recovery Framework describes community as a "network of individuals and families, business, governmental and nongovernmental organizations and other civic organizations that reside or operate within a shared geographical boundary and may be represented by a common political leadership at a regional, county, municipal or neighborhood level" (FEMA, 2011a, p. 79). This definition is incomplete in the context of resilience to dam or levee failure. Floods and their direct and indirect consequences recognize no municipal or political boundaries. A distinctly different definition of a community describes its members as having common interests (e.g., NRC, 2011a)—in this case, the continued safe functioning of dam and levee infrastructure. They may also share broad development goals and their social behavior and relationships governed by common specific social norms (Agrawal and Gibson, 1999).

This chapter expands on the definition of community and defines what makes a community resilient.

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CHARACTERISTICS OF A RESILIENT COMMUNITY

The committee identifies three key features of resilient communities. First, a resilient community is able to assess and minimize potential threats. Second, a resilient community uses its social and physical infrastructures and lifeline systems effectively to communicate and coordinate activities to mitigate, prepare for, respond to, and recover from disasters. Third, a resilient community has the capacity to adapt and learn from change and adversity—its own and those of others.

Capacity to Assess and Minimize Potential Threats

A resilient community has the capacity to understand the benefits of dam and levee infrastructure and the ability to assess, anticipate, and minimize potential threats over the short and long terms while retaining its basic structures and functions. Resilient communities are able to assess and manage risks, are generally well informed of threats, are clear about the roles and responsibilities of individuals and organizations in the community with respect to risk, and maintain safety programs and—in this case—water management programs in ways that strengthen the community's ability to mitigate potential infrastructure failures.

Many solutions may be available to community members and stakeholders to minimize the effects of floods, including risk reduction and mitigation, financial planning, and insurance. Without a clear understanding of the limitations of flood mitigation infrastructure, community members and stakeholders are likely to be ill-prepared for emergencies that might place lives and livelihoods at risk. When a community fails to appreciate its exposure to floods and their consequences, there may be little support for investment in the maintenance and upgrading of infrastructure, such as dams and levees.

When there is limited availability of dam and levee flood hazard and consequence information, as will be discussed in Chapter 3, it is difficult or impossible for communities and stakeholders to identify vulnerable regions, people, or institutions. Many, therefore, are unaware of the community's exposure to physical (casualties and damage) and social (economic, psychosocial, sociodemographic, and political) risks (e.g., see Lindell et al., 2006, for a description the social impacts of disaster). They may have inadequate means of identifying risk scenarios or quantifying their risk, and have little reason to consider risk in hazard mitigation or emergency planning. Uninformed community members and stakeholders may not fully appreciate the benefits or limits of protection offered by dams and levees, nor will they adequately understand the commitment required to maintain the benefits over the long term.

Understanding personal, financial, and other types of risk associated with the variety of potential dam and levee failure scenarios is a starting point for enhancing community

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resilience. In the case of investors and financial institutions, flood-related financial risk may not always be recognized or understood, especially if the institutions are managed from outside the immediate region of the dam or levee infrastructure. A major dam or levee failure in one location can have repercussions for commercial risk managers, and enterprise- and supply-chain risk management anywhere in the world.

The public faces numerous and competing risks related to natural hazards. Focusing public attention on risks that are relatively low from a probability perspective (e.g., the risk of dam failure) is difficult, even if the consequences are very high. It is important that decision makers understand and appreciate the nature of potential flood hazards and the range of potential outcomes so that they can assess the effects on livelihood and the options available to reduce risk through avoidance, mitigation, or risk transfer (such as through insurance).

Effective Communication and Coordination

Disaster preparedness—including efforts to inform the public of risks and of response options—occurs before infrastructure failure. A resilient community is able to communicate and coordinate effectively among those with important roles in community disaster mitigation, emergency preparedness and response, and in recovery, as well as with civic, business, and other community leaders. Resilience is largely dependent on trust—building trusted relationships between community leaders, members, and stakeholders. If community members trust their leaders, they are more likely to be responsive to the information their leaders disseminate. Stakeholders more broadly may not have the same kind of relationship with local community leaders, and therefore communication with them must be purposeful and targeted to build trust. In addition to the ability to prepare for disaster, a resilient community has the ability to respond rapidly when failure occurs; this may involve, for example, arrangements for rapid mobilization of coping resources to facilitate effective and timely restoration of services and a rapid return to normal functioning.

Capacity to Adapt

A resilient community has the ability to learn from disastrous events that occur locally or elsewhere, and is able to institute measures to safeguard the community from future events. A community may learn that the former status quo may not be in its best interest if that way of functioning could be sustained as a result of a disaster. A "new normal" that is resilient to known hazards might be more appropriate. Resilient communities take advantage of opportunities to increase community security and robustness, resulting in even greater resilience.

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ENGAGING ALL ELEMENTS OF A COMMUNITY FOR RESILIENCE

Legal authority is the regional or local formal leadership structure, including elected, appointed, and statutory authorities that make up an area's regulatory framework. Representatives of this group have primary responsibility for ensuring the safety and well-being of citizens (e.g., WMO, 2006) and include local administrative units responsible for emergency planning, risk and emergency management, mayors, governors, and legislators. Decision making, however, is complex and sometimes politically charged, as might be expected in the case of multijurisdictional regions, or where decisions regarding resilience are driven by special districts, the private sector, or citizen interests. In many cases, mayors or city managers may be primary representatives of the authority in communities; in others, it may be emergency management personnel. Authority may overlap or be ill-defined. Decisions related to safety and well-being are also made by many others in the community, including dam and levee professionals and members of the wider economy. In some cases, the framework that drives disaster resilience-related decisions may be in the form of private–public collaboration (see NRC, 2011a).

Community engagement, such as private–public collaboration, is an effective means of enhancing community disaster resilience if all those engaged are equally vested in the outcomes (e.g., NRC, 2011a). However, community-wide resilience will be enhanced only when all elements of the community are considered. Deciding whom to engage requires careful examination of community elements. A community, as broadly defined in this report, can be divided into four major elements:

- Dam and levee professionals
- Persons and property owners at direct risk
- Members of the wider economy
- Social–ecological systems

Those elements, the communication links among them, and their roles in enhancing community resilience are described in the next sections and in Table 2.1. All groups represented in Table 2.1 are functionally interdependent in some way. Resilient communities are able to recognize those interdependences and capitalize on them to increase the capacity to assess and minimize disaster risk; to communicate and coordinate effectively to enhance resilience among all elements of the community; and to develop the capacity to adapt to change as warranted. The committee, however, acknowledges that such interdependences are often better defined for communities influenced by dams than for those influenced by levees.

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Dam and Levee Professionals

Dam and levee professionals are the individuals and organizations concerned with the planning, design, construction, maintenance, operation, and regulation of physical modifications of river or coastal systems. This includes what is conventionally considered the "dam safety community" and its counterpart for levees and other flood-protection infrastructure. Members of this sector are defined by their occupation or organizational responsibility, not by proximity to flood control works or exposure to risk. Table 2.1 shows that this element is responsible for a wide variety of activities. Its activities and responsibilities differ substantially between times of normal operations and times of unusual events.

Persons and Property Owners at Direct Risk

People who live, work, or own property in an inundation zone experience a different kind of risk from others in the community: possible loss of life, limb, property, or workplace as a direct result of inundation. The effects are on them or their real or personal property. Potential damages derived from the inundation itself and associated water quality issues exist whether or not people participate in the regional economy or any social–ecological networks. Table 2.1 lists representative losses for this element of the community. Under normal conditions, members of this element are likely to have little flood-risk–related communication with dam and levee professionals or with agents of the wider economy.

Members of the Wider Economy

Many individuals and organizations may experience flood-related consequences as a result of their participation in the area economy, either as producers of goods and services for a region at risk of flooding, or as consumers of goods and services exported from those areas. Small businesses, financial institutions, and any other locally significant business that may be forced to close can affect local economies. Examples of the type of individuals and organizations in this group in the private and public sectors are listed in Table 2.1. Those with input regarding funding for dam and levee infrastructure development, operation, and safety are also members of this category.

Direct effects on private- and public-sector entities can be related to, for example, flood damage of highways, power lines, telecommunication services, pipelines, water services, and other utilities; loss or deterioration of fisheries habitat; and changes in water quality. Firms and government agencies directly affected include ones that suffer physical damage, lose complete or partial capacity to move materials or employees, and are unable to operate because of flood-related labor-force dislocation. Indirect effects can result in lost market for goods and services, supply-chain disruptions, or loss of demand for goods and services.

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TABLE 2.1 Elements of the Dam and Levee Safety Community

Element	Example Components
Dam and levee professionals	Dam and levee owners, operators, and regulators; water-related service agencies and organizations, including • Federal and state regulatory agencies • Regulation enforcement and oversight agencies • Municipal water supply utilities • Hydropower generating facilities • Agricultural irrigation districts • Water-based recreation providers and suppliers Individuals and organizations activated in the event of failure or threat of failure: • Emergency management agencies • First responders and law enforcement • Key political leaders • Some large employers
Persons and property owners at direct risk	Individuals or organizations at risk, due to flooding or water-quality issues, for direct consequences to themselves or property such as loss of life or limb; damaged or lost real or personal property; costs of short- and long-term evacuation and recovery (including social capital); lost employment or wages due to evacuation, transportation disruption, etc.; closed schools and childcare; and lost government infrastructure (e.g., police, fire, transportation, water, and sewer).
Members of the wider economy	Individuals and organizations at risk for economic consequences directly or indirectly related to flooding or water quality issues, including • Private-sector manufacturing, warehousing, and retailing firms • Large and small locally significant businesses • Real estate developers • Utility companies • Shareholders • Banks and other mortgage holders • Insurance companies • Public and private agencies providing services, such as health care, education, personal services, and recreational services • Floodplain management organizations • Land-use planning and zoning agencies • Government officials engaged in economic development and related subjects • Government and private individuals involved in dam and levee infrastructure development and operation funding decisions

continued

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TABLE 2.1 Continued

Element	Example Components
Social–ecological system	Institutions and organizations that may serve as advocates, contribute to community involvement and mobilization, and have political influence, including • Institutions involved in governance (including water quality regulation) • Nongovernment and not-for-profit organizations (e.g., American Red Cross) • Political networks • Social networks, such as indigenous and other populations or groups • Communication networks • Mass media entities that, for example, can raise awareness, communicate risks, expose and cover floods, and disseminate post-disaster performance reviews • Social support networks • Neighborhood or citizen corps networks • Family networks • Religious networks and other faith-based organizations • Environmental organizations and cultural resources • Biodiversity • Natural resources • Cultural heritage sites and resources • Private volunteer organizations • Chambers of commerce

The firms and agencies that suffer indirect effects are not necessarily in or near the potential inundation area. Recent flooding in Thailand, for example, has highlighted how complex manufacturers' supply chains can be and how the overall effect of localized flooding can easily be underestimated. According to A.M. Best,[1] "given the floods' impact on manufacturing in Thailand's industrial estates, one of the major uncertainties will come from the difficulties in calculating contingent business interruption losses" (A.M. Best, 2012, p. 1). If the corporate governance process does not anticipate the effects of flooding, the institutions might not be able to meet financial obligations. Similarly those with decision-making power related to the funding of dam and levee infrastructure itself may not be fully informed of risks and what is necessary to make such infrastructure "safe." Long-term funding, whether by executive budget management agencies or independent entities, may not be part of dam or levee safety decision processes.

[1]The A.M. Best Company is a credit-rating organization that serves the insurance industry.

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The Social–Ecological System

Social systems are structures created by interacting individuals and organizations for the purpose of achieving common goals (see, e.g., Parsons, 1951). In dealing with resilience associated with dam and levee infrastructure, social systems noted in this report focus largely on governance issues, such as property rights and access to resources, the dynamics of environment and resource use, and world views and ethics that address human–nature relationships. Ecological systems are self-regulating communities of organisms that interact with each other and their environment. Social and ecological systems are closely linked, and changes in one inevitably have reverberations in the other (e.g., Milestad and Hadatsch, 2003). The concept of a social–ecological system is useful in this report for considering the actions of humans in nature and for human management of surface water and groundwater. Networks of various kinds exist in these systems, including, in the case of this report, aquatic animals and plants, institutions and organizations involved in governance, and networks of people and their values that make up the community. Of concern in current analysis and management is the ability of social–ecological systems to adapt to novel challenges without compromising sustainability (the topic of several papers found in Berkes et al., 2003).

The social–ecological system is complex, dynamic, and subject to continuous evolution and adaptation. A sustainable system requires continuing interactions between nature and people, interactions on multiple scales (local to global) within the social, economic, and governmental domains, and a basic concern with resilience—the capacity of the system to withstand change and disturbances and adapt by incorporating input information and assessing feedback resulting from prior changes. It also includes people and institutions not in the proximate inundation zone. Explicitly addressing risk, uncertainty, equity, ambiguity, ignorance, and surprise by those with a common interest in a specific dam or levee safety situation can help to define affected networks. Of concern in current analysis and management is the ability of the social–ecological system to adapt to novel or emerging challenges without compromising sustainability.

IMPLICATIONS FOR ENHANCING RESILIENCE

Resilient communities are ones that develop long-term strategies with an "all-hazards approach" to disaster management—consideration of all manner of threats to the health, economy, and proper functioning of the community—rather than strategies focused on a single emergency action plan.[2] Building and maintaining infrastructure critical for the long-

[2]An all-hazards approach has long been encouraged for disaster preparation nationwide as reflected and reinforced in such recent documents as the Stafford Act (see www.fema.gov/about/stafact.shtm, accessed December 20, 2011), the Post-Katrina Emergency Management Reform Act (see frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=109_cong_bills&docid=f:s3721is.txt.pdf, accessed December 20, 2011), and Homeland Security Presidential Directive 5: Management of Domestic Incidents (see www.dhs.gov/xabout/laws/gc_1214592333605.shtm#1, accessed December 20, 2011).

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term prosperity of a region, including dam and levee infrastructure, are elements of those strategies. However, the benefits provided by such infrastructure may be taken for granted, and risks overlooked. The community could suffer for not having recognized potential risks before a disastrous failure.

General Benefits of a Fully Engaged and Informed Community

In the case of community resilience with respect to dam and levee safety, improved communication before, during, and after controlled or uncontrolled flow resulting in flooding is part of holistic planning that makes timely mitigation, preparedness, response, and recovery more successful. In many communities today, dam and levee owners and operators, emergency managers, financial risk managers, and other decision makers are uninformed of the potential risks associated with dam or levee failure. Their decisions, then, will probably not be the most beneficial for themselves or their communities, and may place their communities in grave danger if a dam or levee failure occurs. As part of an engaged community whose elements (as described in Table 2.1) collectively agree to enhance dam and levee safety and community resilience, decision makers—including dam and levee owners and operators—should be informed and aware of the benefits and hazards associated with the dams and levees that support their livelihood. Their decisions may allow communities to

- *Obtain sufficient resources to maintain dam and levee infrastructure.* Collaborative engagement between dam and levee professionals and the broader community may lead to improvements that minimize risks identified collectively as most consequential. A community's awareness of flood infrastructure encourages its financial participation in ongoing maintenance and upkeep of dams and levees, which leads to more comprehensive advanced planning for likely floods. Box 2.1 provides an example of how community awareness can facilitate procurement of needed maintenance resources.
- *Enhance preparedness.* All planning for potential scenarios and emergency response—whether focused on primary life and safety concerns, the preservation of property, or preservation of physical and social infrastructure—require understanding of potential emergency scenarios by all community elements. The community, including dam and levee owners, can collectively identify dam and levee infrastructure and associated flood risks. They can then identify other community risks and resources, and enhance preparedness by collectively prioritizing preparedness goals and choosing appropriate mitigation and preparedness activities.
- *Improve regional emergency response*. Effective disaster response depends on already having open lines of communication with those in and outside the community able to provide information and resources during times of need (see, e.g., NRC, 2011a), whether local, regional, or federal emergency support personnel or through

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BOX 2.1
Building Community Awareness

The Miami Conservancy District in southwest Ohio[a] (see Figure) is engaged in efforts to build community awareness and improve the understanding of the benefits brought by the locally designed, constructed, operated, and maintained surface-water management system that includes five "dry dams and 55 miles of levees in 11 cities" (Rinehart, 2011) The conservancy was created to manage flood protection in the Great Miami River after the disastrous floods of 1913. It has received no federal or state funding and relies entirely on local funds, assessed annually, from about 48,000 households and businesses—the beneficiaries of the flood protection system. The Conservancy is an example of a comprehensive systems-based holistic approach with a well-established governance process. The key message to stakeholders is the concept of sustainability linking economic, quality-of-life, and environmental benefits of the work of the district.

Miami Conservancy District, Ohio. SOURCE: Rinehart (2011). Reprinted with permission from the author, copyright 2011.

[a]See www.miamiconservancy.org/ (accessed December 20, 2011).

financial planning. Engagement builds familiarity and trust. If a decision maker trusts the person with whom he or she is engaged, decisions will be made quickly and with more confidence during an emergency situation. Strategies to strengthen community resilience include building and maintaining such relationships with interested parties in and outside the immediate community; all involved need to

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be aware of their roles and prepared to respond. This includes early engagement with regional and federal emergency support entities and personnel. For regional emergency response to be effective and sustainable, critical individuals need to be aware of their roles and prepared with adequate resources ranging from personnel, to supplies, to financial support.

With fewer disruptions to community functions, recovery can be expected to occur more quickly. Understanding the interdependencies among community elements promotes recovery of individual elements. Established communication networks will facilitate the difficult tasks of assessing and relaying the status of major and minor community functions following an event, and resources can be directed to restore function where needed. New operational norms can be adopted quickly if necessary. Benefits of engagement are described more fully in Chapter 4, including benefits to dam and levee safety professionals and benefits to other members of the community.

Information-Related Barriers to Effective Resilience-Focused Engagement

There are challenges to effective resilience-focused engagement, many of which are related to access to or understanding of inundation-related data and a community's flood-risk profile. Incomplete understanding of the benefits, hazards, and risks associated with dams and levees hampers effective community engagement and decision making. Below are some of the major information-related barriers to effective engagement and informed decision making.

- *Information regarding the locations of dams and levees and the areas they protect is not consistently available in the public domain.* After the events of September 11, 2001, the public is not granted routine access to inundation maps (USACE, 2008; DOI, 2011; see Box 2.2 for response to similar directives abroad), although recent initiatives make some inundations maps more accessible.[3] Without the most basic information, communities engaged in resilience-focused collaboration cannot make informed decisions. FEMA itself can be affected by the lack of data, as can, for example, the private insurance industry.[4] Resources allocated to support emergency responders may also be affected.

[3]For example, see geo.usace.army.mil/egis/cm2.cm26.map?map=mvd_ows (accessed May 21, 2012).

[4]The private insurance market that provides property insurance to those seeking additional coverage beyond that provided by the National Flood Insurance Program relies on FEMA flood maps to identify flood hazard domains. The amount of coverage provided depends on the size of the entity purchasing insurance—larger institutions and industrial companies may purchase in excess of $100 million of flood insurance. Insurers typically manage their own known flood risk conservatively by applying larger deductibles, by using insurance limits, or by purchasing reinsurance. Where flood maps are unavailable, private insurers rely on historical claims data to make actuarially based decisions; such decision-making occurs without knowledge of potential flood hazard (C. Goodwin, personal communication, February 11, 2011).

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Dam and Levee Safety and Community Resilience: A Vision for Future Practice

BOX 2.2
Response to the 2007 Floods in the United Kingdom: Make Data Available

Countries in different parts of the world have responded to national security threats by withholding information from the public that potentially could be used to plan terrorist attacks against critical infrastructure. There is growing recognition, however, of the advantages of having data regarding flood hazards accessible to the public. An investigation of the 2007 floods in the United Kingdom resulted in the Pitt Review (DEFRA, 2008) and included 92 recommendations for building community resilience to flood hazards. The report describes that "large-scale natural events are more probable and have higher consequences than terror" and it welcomes an approach to risk management that balances the risks of terrorism against natural hazards "in a single plan" (p. 245). The report also includes this statement:

> The Government should provide Local Resilience Forums with the inundation maps for both large and small reservoirs to enable them to assess risks and plan for contingency, warning and evacuation and the outline maps be made available to the public online as part of wider flood risk information. (p. 306)

In its response to the Pitt Review (DEFRA, 2008), the government of the United Kingdom indicated that it supported this recommendation, and it began providing basic-level inundation maps to local resilience forums while preparing more detailed maps of higher-risk reservoirs. As of December 2009, the government had completed protocols for sharing the maps developed (DEFRA, 2009). Web-based search tools were also being developed for the public.

- *FEMA flood maps are easily misunderstood.* FEMA flood maps prepared to support the National Flood Insurance Program[5] show the areal extents of flooding for what are termed 100-year flood events,[6] and, when information is available, the elevation of the base flood. Those maps often represent the best technical information available to communities. Those who seek flood hazard maps may use FEMA flood insurance rate maps, perhaps mistakenly believing these maps detail a full range of flood hazards. Dams and levees designed to control water flows of magnitudes greater than a 100-year flood event are routinely not shown on FEMA flood maps. Communities may be unaware of the existence of local or upstream dams and levees and their related risks. Because readers uninformed of the intent of the flood insurance maps may draw erroneous conclusions regarding safety, the result may be misinformed personal or community- level decisions.

[5]For example, see msc.fema.gov/webapp/wcs/stores/servlet/FemaWelcomeView?storeId=10001&catalogId=10001&langId=-1 (accessed December 21, 2011).

[6]A 100-year event, also called a once-in-a-100-years event, is one with an annual exceedance probability of 0.01 (1.0%). A 100-year event can occur at any time; the probability of occurrence in any given year is 0.01 (1.0%).

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BOX 2.3
An Unwarranted Sense of Safety?

A 2001 study conducted by Pfister (2002) of the evacuation of Grafton, New South Wales, Australia, before a flood event addressed perceptions of flood risk. A local river was expected to rise to a height 0.13 m below the expected height of protection offered by local levees. Because of uncertainties inherent in river-crest predictions, the town was ordered to evacuate, but fewer than 10 percent of the population are estimated to have evacuated (Pfister, 2002). Pfister noted that "the residents of Grafton, having experienced few direct effects of flooding since the construction of the levees, are likely to have developed a relatively low consciousness of the flood threat, and are therefore less ready to act" (Pfister, 2002, p. 24).

- *Available data can lead to an unwarranted sense of safety*. Those living or working in a region protected by a levee may consider themselves immune to flooding, especially given a lack of data, incorrect data, or misinterpretation of available data. Box 2.3 is an example of a community that largely failed to adhere to a flood evacuation order, apparently because it lacked awareness of the flood threat. Communities behind levees and dams may believe they are "safe," and may not fully understand the value of the infrastructure, the need to maintain it, or the actions to be taken in the event of failure.

BUILDING SOCIAL CAPITAL FOR COMMUNITY RESILIENCE

Social capital refers to the connections among social networks that can be used, through collaboration, to obtain societal goals—in this case, community resilience. The concept of social capital has been in the sociologic, economic, and political science literature for several decades; one of the earliest uses of the term was by Hanifan (1916). Political scientist Robert Putnam and coauthors developed the concept in *Making Democracy Work: Civic Traditions in Modern Italy* (Putnam et al., 1993). Putnam et al. explain the dilemmas of collective action and how they can be overcome by a stock of social capital, by the existence of networks of civil engagement, and through norms of reciprocity—the expectation that people will treat or serve others as they themselves have been treated or served. He attributes the emergence of democratic institutions, behavior, and social trust to the growth of participation in voluntary organizations in which people acquire skills and develop expectations with respect to social behaviors. These skills include the ability to negotiate, compromise, work together, and provide leadership. They are assets, sometimes described as moral resources, that may be useful for building community resilience because people learn to cope together to solve

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problems and deal with common stressors. Putnam developed the notion of social capital further in his later work, *Bowling Alone: The Collapse and Revival of American Community* (Putnam, 2000), in which he explores how and why Americans have become disconnected from one another and how social structures and institutions have atrophied. He concludes that social capital is best built by a dense network of voluntary organizations and widespread public participation in them.

The concept of social capital has been broadened by including it in a larger framework that also includes natural capital, human capital, and financial capital. The framework has been used by development agencies, such as the United Kingdom's Department for International Development, to assess a country's development potential and its actual or potential vulnerability to stresses and perturbations. Social capital has been described as the foundation for community adaptation (see, e.g., Norris et al., 2008; NRC, 2011a) with "the formation of effective and productive social networks as the key element in [its] development" (NRC, 2011a; p. 106). Social capital and therefore community resilience could be enhanced via

- dense community social networks that build communication and social interactions in a community or among people and organizations that have a common interest;
- widespread voluntary organizations that afford community members opportunities for participation and collaboration;
- development of community members' skills in negotiation, compromise, and leadership as a result of participation in voluntary organizations and social networks;
- widespread access to and use of social media;
- development of a network of private and public partnerships in the community.

The development of social capital, in turn, fosters higher social trust in the community, unquestionably a valued resource for effective risk management and decision making with respect to dam and levee safety. Chapter 4 provides a comprehensive discussion of how it is applied specifically to the dam and levee safety community.

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CHAPTER THREE

Current Dam and Levee Infrastructure, Management, and Governance

This chapter summarizes current dam and levee physical infrastructure, and management approaches with respect to safety, including methods and standards used in design, inventory, operation and maintenance, and emergency management. It also addresses the governance framework in place to facilitate and guide dam and levee safety, including the legal framework and the roles and authorities of agencies at different levels. Gaps in current practice and governance related to fostering community resilience are identified. Because policies, management, and jurisdictional responsibility for safety differ between dams and levees, this chapter describes dam and levee issues separately.

"Safety" to many dam and levee professionals is associated primarily with reducing the likelihood of flooding. Dam safety efforts since the 1972 failure of Buffalo Creek Dam[1] have therefore focused on strengthening safety programs, reducing the potential for future failures, conducting periodic inspections, remedying deficiencies, and preparing emergency action plans (EAPs). Progress in those endeavors has been substantial on a national scale. There has also been consistent movement in recent years toward risk-informed dam safety assessments among many dam owners. Development of EAPs and the carrying out of tabletop and full-field exercises have also become established dam safety practices among many owners.

Despite such challenges as limitations in safety program resources, a large number of dams rated as having "high" or "significant" potential of death or loss of property in the event of failure (see Box 3.1 for description of the rating system) are inspected in a timely manner according to guidance from the Association of State Dam Safety Officials (ASDSO)[2] (e.g.,

[1]Information about the Buffalo Creek Dam failure can be found at www.wvculture.org/history/disasters/buffcreek govreport.html (accessed December 23, 2011).

[2]ASDSO was established in 1983 and represents state, federal, and local dam professionals, academics, and manufacturers and suppliers. The organization was established to provide guidance for nonfederal dam owners. Although it holds no regulatory authority, it has played a major role in coordinating dam safety efforts across the country and between the states and the federal agencies. It has been the major advocate for dam safety policy, technical guidelines, and training. See www.damsafety.org/about/?p=1ca717dd-18d5-4803-a7eb-cd45aad31210 (accessed February 7, 2012).

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Dam and Levee Safety and Community Resilience: A Vision for Future Practice

BOX 3.1
Dam and Levee Hazard Classification

The National Inventory of Dams (NID) hazard classification system (see Table 1) is broad, qualitative, and based on the potential threat to life and property in the event of dam failure. The criteria for inclusion in the inventory are provided in Table 2. A dam is given a "high" hazard rating if its failure can result in fatalities, whether the dam is small or large and has the potential for a single or thousands of fatalities. The rating is also regardless of its condition (e.g., its likelihood of failure). Current emphasis is appropriately on high-hazard dams, but there can be a wide disparity in the consequences of failures of these structures. Other consequences of dam failure, such as economic and environmental losses, are qualitatively evaluated

TABLE 1 Hazard Classification for Dams

Hazard Classification	Likelihood of Loss of Human Life	Likelihood of Economic, Environmental, or Lifeline Loss
Low	None expected	Low and generally limited to owner
Significant	None expected	Yes
High	Probable; one or more expected	Yes (but unnecessary for this classification)

SOURCE: FEMA (2004b).

ASDSO, 2005). As a result of these inspections, many dams have undergone safety modifications for hydrologic, seismic, and other deficiencies. But efforts to improve dam safety are not complete; about half of the dams that should have EAPs do not (Altinakar et al., 2008; see Box 3.2), and there is a backlog of safety repairs to be addressed. Moreover, improving safety needs to be a continuing and adaptive process that is responsive to changing structural and societal conditions. The concept of safety among dam and levee professionals has not evolved beyond reducing the likelihood of failure.

DAM AND LEVEE INFRASTRUCTURE

Before a community can address risks associated with dam or levee failure, it must know that a dam or levee is present and poses risk. Information on dam and levee location, physical properties (e.g., size and type), design requirements, ownership, maintenance responsibility, and regulatory framework is critical for understanding the hazards and risks

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and defined in equally broad terms. The hazard classification process does not include an assessment of the sociological or other effects on a community, nor does it consider the broader local and regional effects (economic and other) of the loss of a critical infrastructure (power, water supply, flood protection). Hazard classification is assigned primarily by state or federal regulatory agencies. The Federal Emergency Management Agency guidance states that classifications "should be based on the worst-case, probable scenario of failure or mis-operation of the dam, i.e., the assigned classification should be based on failure consequences that will result in the assignment of the highest hazard potential classification of all probable failure and mis-operation scenarios" (FEMA, 2004b, p. 7).

TABLE 2 National Inventory of Dams, Dam or Reservoir Size Criteria

Category[a]	Criteria	Excluded
Dam height	Over 25 ft	6 ft or lower, regardless of reservoir capacity
Reservoir size	At least 50 acre-ft	Maximum, 15 acre-ft or less, regardless of dam height
Hazard	Any dam that poses a "significant threat to human life or property in the event of its failure"	

[a]Height is measured from the dam crest to the downstream toe; size is reservoir impoundment capacity.
SOURCE: USACE (2011a).

associated with the infrastructure. The National Inventory of Dams (NID) and the National Levee Database (NLD) were established to provide information about dams and levees in the country. The next sections describe those inventories and information in them about dam and levee physical infrastructure and ownership.

National Inventory of Dams

The National Dam Inspection Act of 1972,[3] passed after the failure of multiple dams, required the U.S. Army Corps of Engineers (USACE) to create the NID. The first version of the NID was delivered in 1975, and is generally updated on a 2-year cycle (the last update was in 2009).[4] Since 1975, the NID has been managed by USACE or the Federal

[3]See Public Law 92-367 (available at npdp.stanford.edu/ndia.html).
[4]See damsafety.org/media/Documents/PDF/2009NIDupdate_March2010.pdf.

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BOX 3.2
Emergency Action Plans

An Emergency Action Plan (EAP) identifies the actions and responsibilities of different parties in the event of an emergency, including uncontrolled flow from a reservoir or other controlled waters. As defined by FEMA (1998, p. 3), an EAP for a dam is

> a formal document that identifies potential emergency conditions at a dam and specifies pre-planned actions to be followed to minimize property damage and loss of life. The EAP specifies actions the dam owner should take to moderate or alleviate the problems at the dam. It contains procedures and information to assist the dam owner in issuing early warning and notification messages to responsible downstream emergency management authorities of the emergency situation. It also contains inundation maps to show the emergency management authorities the critical areas for action in case of an emergency.

The requirements for EAPs are established by dam safety regulatory agencies at the national level, by such individual agencies as the Federal Energy Regulatory Commission, or by individual states. Figure 1 indicates that 48 percent of high-hazard dams that should have EAPs do not (Altinakar et al., 2008). Figure 2 indicates that about 71 percent of significant-hazard dams do not have EAPs (Altinakar et al., 2008). EAP oversight occurs primarily at the state level, but EAPs are examined by the Association of State Dam Safety Officials and the National Dam Safety Review Board. The latter two organizations have no authority to mandate revisions of EAPs to make them more effective, and state agencies often operate under tight budgets, making EAP oversight a challenge. Nevertheless, EAPs serve important functions for the dam owners and the broader community. Consequences of not having an EAP have been demonstrated, for example by the 1982 failure of the Lawn Lake Dam in the Rocky Mountain National Park in Colorado which caused the deaths of three people and $31 million in damage (NPS, 2004). A district court found that the government "in creating this relationship with citizens, also creates a duty for itself to develop orderly procedures for dealing with emergencies."[a]

EAP effectiveness is dependent on the correctness of the underlying assumptions (e.g., accurate estimation of risks and appropriate responses), reasonable care in the regular review and modification of plans, and appropriate education and training of those with responsibility in the execution of the plan.

[a]See Coates v. United States, 612 F. Supp. 592 (C.D. Ill. 1985).

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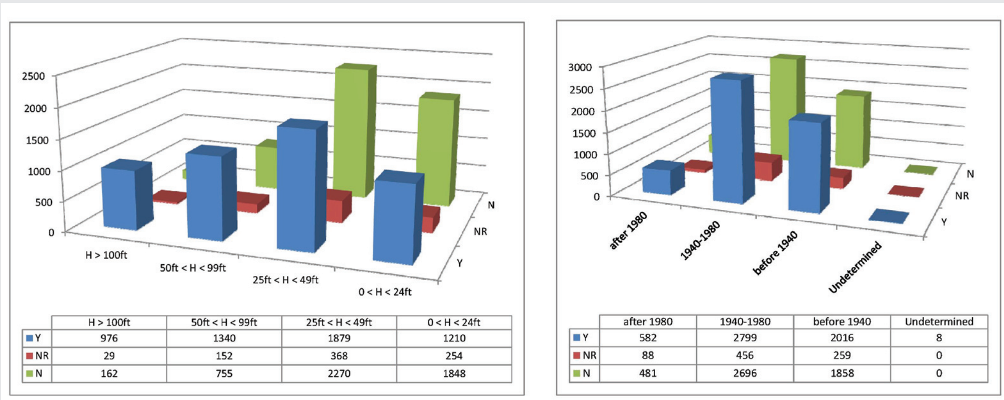
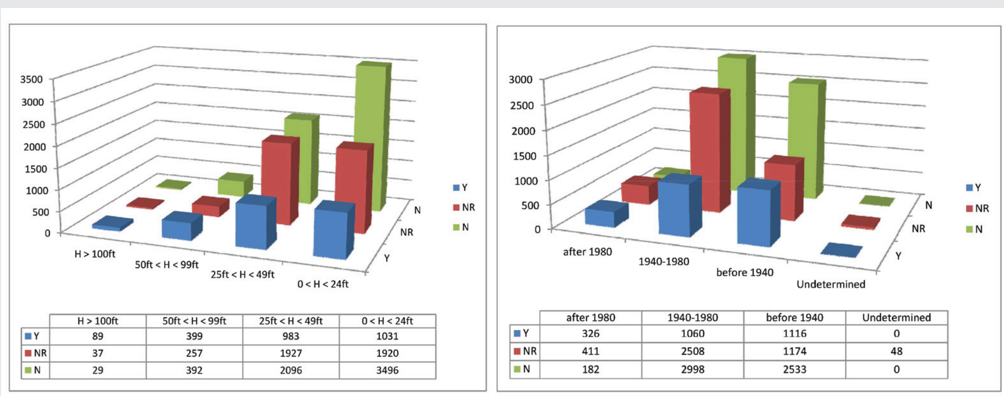


	H > 100ft	50ft < H < 99ft	25ft < H < 49ft	0 < H < 24ft
Y	976	1340	1879	1210
NR	29	152	368	254
N	162	755	2270	1848

	after 1980	1940-1980	before 1940	Undetermined
Y	582	2799	2016	8
NR	88	456	259	0
N	481	2696	1858	0

FIGURE 1 (a) Classification of high-hazard dams by height vs status of EAPs. (b) Classification by age vs status of EAPs. Based on entries in National Inventory of Dams as of September 28, 2008. Y = Yes, EAP exists; NR = EAP not required; and N = No, EAP does not exist. SOURCE: Modified from Altinakar et al. (2008). Used with permission from the authors, copyright 2012.



	H > 100ft	50ft < H < 99ft	25ft < H < 49ft	0 < H < 24ft
Y	89	399	983	1031
NR	37	257	1927	1920
N	29	392	2096	3496

	after 1980	1940-1980	before 1940	Undetermined
Y	326	1060	1116	0
NR	411	2508	1174	48
N	182	2998	2533	0

FIGURE 2 (a) Classification of significant-hazard dams by height vs status of EAPs. (b) Classification by age vs status of EAPs. Based on entries in National Inventory of Dams as of September 28, 2008. Y = Yes, EAP exists; NR = EAP not required; and N = No, EAP does not exist. SOURCE: Modified from Altinakar et al. (2008). Used with permission from the authors, copyright 2012..

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Emergency Management Agency (FEMA). It is currently maintained and updated by USACE. Before the September 11, 2001, terrorist attacks on the United States, the NID was freely accessible online and distributed on CD. The NID is still online,[5] but information on hazard classifications, locations of nearest downstream towns, and dam conditions are password protected and not available to nongovernment users.

The NID includes information about the location, physical characteristics, dam type, foundation type, designer, owner, and hazard-potential classification of about 84,000 dams. Dams in the database are more than 25 ft high, hold at least 50 acre-ft of water, or are considered to pose a significant hazard if they fail (USACE, 2011a). Dams included in the NID meet the criteria listed in Table 2 of Box 3.1. The hazard-class distribution of all dams in the NID is shown in Figure 3.1. High-hazard dams (at least one death expected in the event of failure) make up almost 17 percent of the inventory. Some 31 percent of the dams in the inventory (those classified as having high or significant hazard potential) are expected to result in economic, environmental, and lifeline losses in the event of failure. Because the states have primary regulatory authority over dams, and because they have different criteria for defining the dams they regulate, the available information on dams that meet the NID criteria varies. Figure 3.2 shows the distribution of dams in the NID. Box 3.3 provides some statistics about the nation's dams derived from the NID.

Since its development, there have been concerns about the accuracy and completeness of the NID. Recently, for example, the state of Washington conducted a focused survey to identify nonpermitted dams that should be in the inventory and regulated by the state (Johnson, 2010).[6] The survey identified 28 dams classified as high-hazard dams (including 11 that had safety deficiencies requiring immediate attention) and 11 classified as significant-hazard dams. According to Washington state, high-hazard dams are those whose failure would place three or more homes at risk downstream, and significant-hazard dams one or two homes.[7]

National Levee Database

The NLD is less mature than the NID, having been initiated as a result of the National Levee Database Authority (Public Law 109-148) following Hurricane Katrina. The NLD was constructed and populated under the authority of USACE and made available online to the public on October 27, 2011. To date, it contains information only on USACE levees. Although the National Levee Database Authority calls for inventorying all levees in the country, state and federal funding has not been made available to gather data on nonfederal levees.

[5]See nid.usace.army.mil (accessed November 4, 2011).

[6]Washington State has jurisdiction over any dam that can impound 10 or more acre-ft of water at the dam crest.

[7]See WAC 173-175-130, *Engineering Design Reports* (available at apps.leg.wa.gov/WAC/default.aspx?cite=173-175-130).

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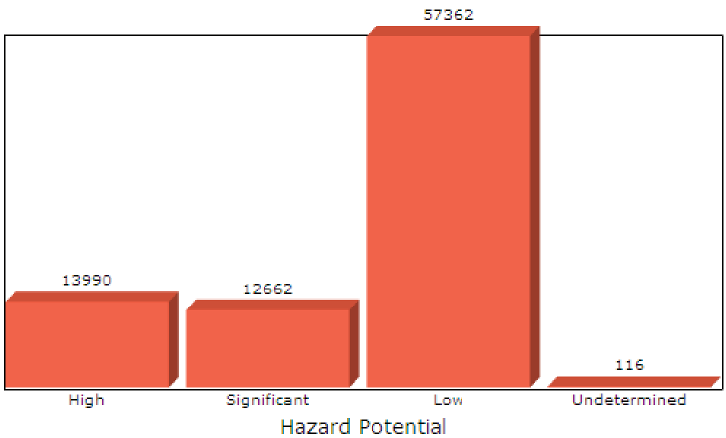

FIGURE 3.1 Hazard-class distribution of dams in the United States. SOURCE: USACE (2012).

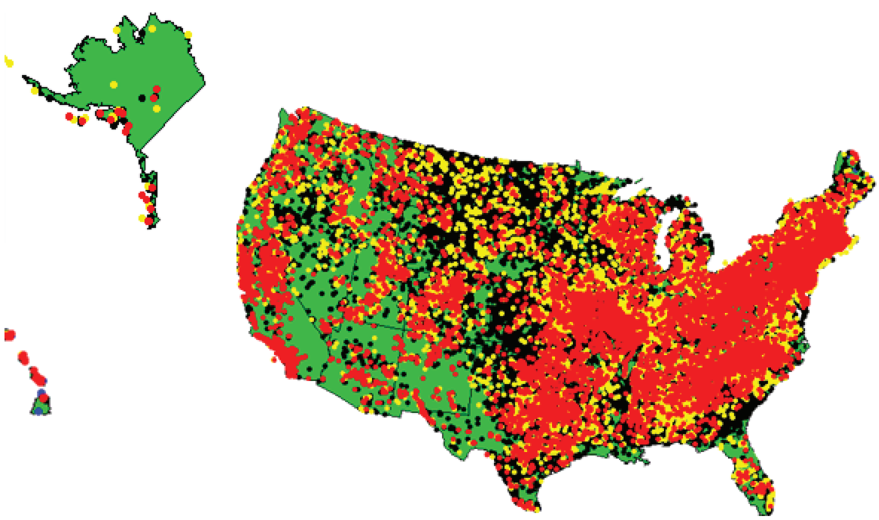

FIGURE 3.2 Distribution of dams cataloged in the National Inventory of Dams. Red dots indicate high-hazard dams; yellow dots indicate significant-hazard dams; and black dots indicate low-hazard dams. Hazard classification refers to the consequences of a dam's failure or misoperation, not to its condition. SOURCE: USACE (2011a).

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BOX 3.3
Characteristics of U.S. Dams Based on the National Inventory of Dams

About 84,000 dams are described in the National Inventory of Dams. Figures 1 and 2 show the distribution of dams by type (e.g., earth or rock embankments and concrete gravity) and by height, respectively. About half the dams are 25 ft or less in height, and the vast majority are earth embankments. Figure 3 shows the distribution of dam completion dates as listed in the NID. About one-third are older than 50 years, and by the end of this decade, about 56 percent will be older than 50 years. Figure 4 shows the distribution of dam ownership in the United States. Nearly 69 percent of dams are privately owned, and less than 4 percent are owned by the federal government. Federally owned dams, however, include many of the largest dams in the country (e.g., Hoover Dam, Grand Coulee Dam, and Bonneville Dam). Only a small percentage of dams in the United States pose a risk to communities.

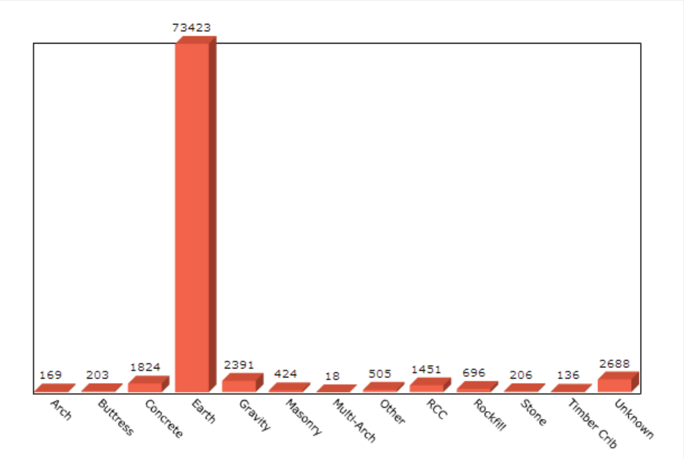

FIGURE 1 Distribution of dams by type in United States. SOURCE: USACE (2012).

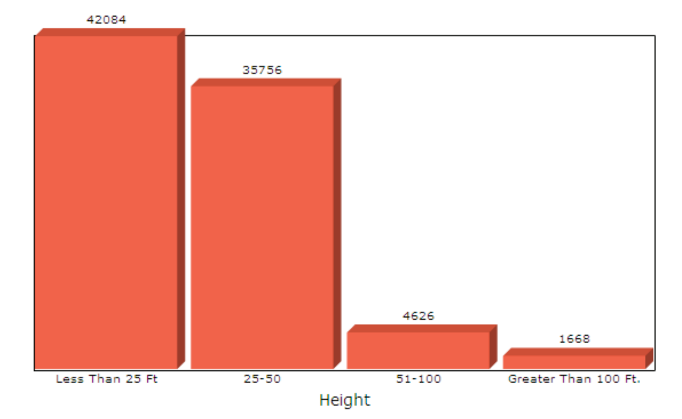

FIGURE 2 Distribution of dams by height in United States. SOURCE: USACE (2012).

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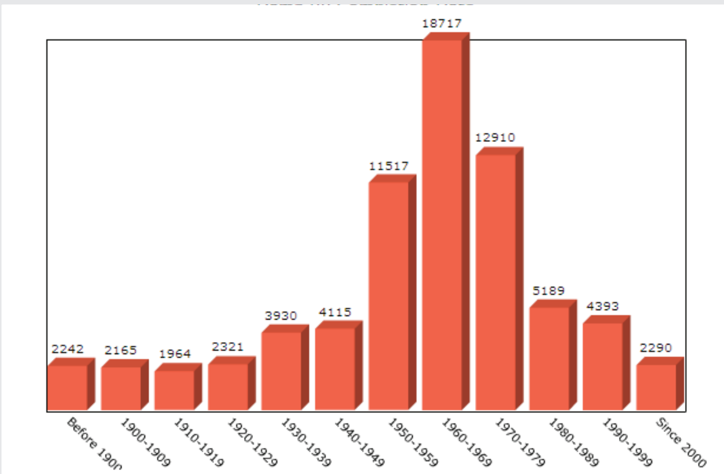

FIGURE 3 Distribution of dams by date of completion in United States. SOURCE: USACE (2012).

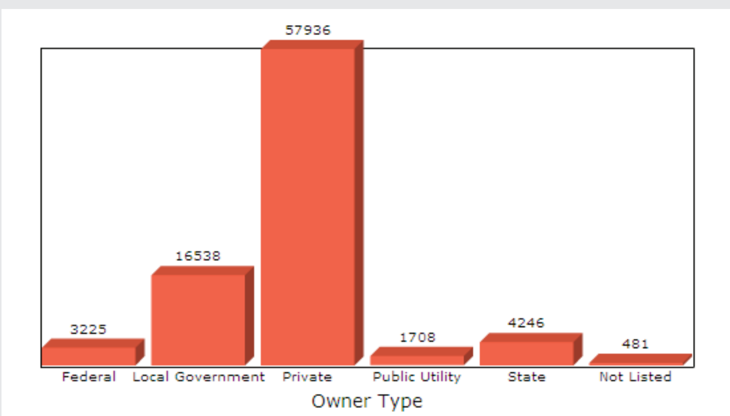

FIGURE 4 Distribution of dams by ownership in United States. SOURCE: USACE (2012).

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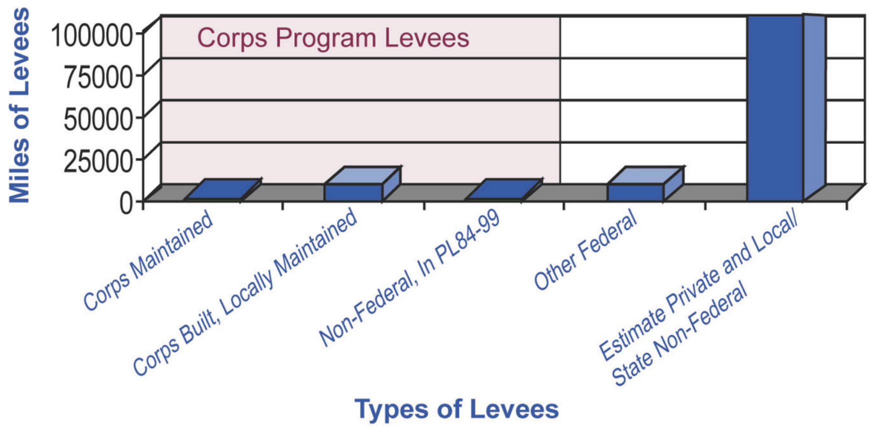

FIGURE 3.3 Distribution of levees by ownership in the United States. SOURCE: NCLS (2009).

Tens of millions of people reportedly live behind levees (NCLS, 2009). The NLD describes about 14,700 mi (22,500 km) of USACE levees.[8] Little is known about the size of the national levee portfolio, especially about levees not under federal jurisdiction. It is estimated that there may be 14,000–16,000 mi (22,500–26,000 km) of levees operated by agencies other than USACE. The National Committee on Levee Safety (NCLS) estimates there may be up to 100,000 mi (161,000 km) of nonfederal levees in the nation (see Figure 3.3). Integration of levee data collected by the FEMA National Flood Insurance Program (NFIP) into the NLD, which is under way, will increase the total number of miles of levee systems in the NLD. More than 21,000 communities currently participate in the NFIP (FEMA, 2011b).

An NLD steering committee that comprises USACE and state representatives has been formed, in part, to begin integrating information on nonfederal levees into the NLD. Some states are making their own efforts to inventory levees. In California, for example, the Department of Water Resources has built a levee database of its estimated 9,000 mi (14,500 km) of nonfederal levees since 1997,[9] effort on which increased after Hurricane Katrina. The inventory is about 30-40 percent complete; a target date for completion has not been set. USACE is developing guidance and providing assistance to states to improve submission of voluntary information for the NLD.

The National Committee on Levee Safety has proposed a levee hazard potential classification system, shown in Table 3.1, similar in overall structure to that for dams (NCLS, 2009). USACE has used this hazard classification system for some of its levees, but

[8]See www.usace.army.mil/LeveeSafety/Activities/Pages/act_nldb.aspx (accessed November 1, 2011).
[9]S. Ekanayake, CA DWR, personal communication, August 10, 2011.

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TABLE 3.1 Proposed Hazard Potential Classification for Levees

Hazard-Potential Classification	Number of People Potentially Inundated	Number of People Potentially Inundated to Depths of 3 ft or More	Additional Considerations
High	≥10,000	≥10,000	Includes areas of consequences where critical life-safety infrastructure is at risk (e.g., major hospitals, regional water treatment plants, and major power plants)
Significant	>1,000	<10,000	Includes areas of consequence where the number of people potentially inundated is low, but there may be significant potential for large economic impacts or losses
Low	<1,000	0	—

NOTE: These classifications use parameters and definitions consistent with those in use by other agencies. For example, California defines an urban area as having 10,000 people and subject to higher flood protection requirements (Senate Bill 5), and FEMA considers shallow flooding to be less than 3 ft (see www.fema.gov/plan/prevent/floodplain/nfipkeywords/sfha.shtm). SOURCE: NCLS (2009).

inspection ratings are not included for most levee systems in the NLD. In October 2011, the state government website *Governing.com* reviewed 744 levee ratings listed in the NLD: 77 percent were found to be rated "minimally acceptable," indicating minor deficiencies that would not impair levee performance; 12 percent were rated "unacceptable," indicating they are not expected to provide reliable flood protection; and the remaining 10 percent were rated "acceptable," indicating they were in satisfactory condition and expected to function (Maciag, 2011). Many of the levees rated as unacceptable may be as much as 70 years old.

Frequent inspections are critical for understanding the condition of levees and the risks that they pose. Updating the NLD with new information is important not only for appropriate risk assessment but also because the NLD could influence how priorities for infrastructure funding are set. Levees operated by USACE undergo routine annual inspections and comprehensive inspections every 5 years. The NLD will be updated regularly as levee conditions change. States might not follow the same inspection schedules.

DAM AND LEVEE SAFETY PROGRAMS

ASDSO distributed a questionnaire to individual state dam safety officials in 2006 to determine what authorities and activities to manage and regulate levee safety existed in the

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states. None of the 48 that responded indicated that their states had comprehensive levee safety programs.[10] The survey also revealed that only 23 states have an agency with some responsibility for levee safety, and only 10 states keep a list of levees within their borders.

Dam safety programs, in contrast, can be much more extensive, with formalized processes for dam engineering and design (including construction inspection and design requirements), periodic dam safety inspections, development of EAPs, and public outreach—all important for increasing community resilience. Programs still vary, however, in criteria and practice. For example, state and federal regulatory agencies have established requirements for periodic dam safety inspection requirements. In general, high-hazard dams are inspected annually and low-hazard dams at 5- to 10-year intervals, but inspection frequencies vary among agencies and depend on hazard classification. Vermont, for example, requires annual inspections for high-hazard dams and mandates that low-hazard dams be inspected every 7–10 years (VTDEC, 2007). Massachusetts has additional inspection guidelines for dams based on size and has an inspection frequency range of 1–10 years (ASDSO, 2000).

The next sections highlight aspects of engineering, design, and public relations in dam safety programs, generalizing some current practices and their contributions to resilience.

Engineering and Design

Deterministic standards-based approaches dominate dam and levee design in the United States; they focus on the engineering design of system components (in the case of dams, e.g., superstructure, gates, intake towers, and spillways). Current standards suggest that hazards be characterized using either deterministic approaches (design flood) or probabilistic approaches (flood based on return period), but uncertainty of structural or system performance is dealt with by using factor of safety approaches rather than probabilistic reliability. Further, standards in place do not take into account infrastructure performance. Factor of safety approaches are limited because uncertainty is not quantified and because they are based on assumptions about relevant failure modes. For example, floodwall levee systems along the outfall canals in New Orleans were designed with a factor of safety of 1.3 (about a 30 percent overdesign to accommodate surprise or unknowns). The failure mode that actually caused structure breach during Hurricane Katrina was not considered in the design—the walls failed before overtopping—and the factor of safety proved inadequate (IPET, 2007b).

USACE has published multiple guidance and engineering memoranda on the design and construction of levees, but few standards are in place for levee design and operation outside of USACE. The criterion established for the NFIP has become a de facto standard for levee design and protection. Current focus on levee designs for 100-year flood protection

[10]M. Ogden, ASDSO, personal communication, September 7, 2011.

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places communities at considerable risk for the larger but less common floods that can cause levee failure. There is a growing interest, however, in the use of risk-based methods to evaluate dams and make risk-informed decisions related to dam safety modifications. Risk-based methods can provide information concerning both the hazard (e.g., the chance of a flood) and the type and severity of consequences (e.g., loss of life, safety, and property). The U.S. Bureau of Reclamation and USACE (since Hurricane Katrina) are using risk-based methods to evaluate dam safety.

Public Relations Versus Public Involvement

Dam and levee safety programs recognize the need for public outreach and public relations; they are vital for building relationships with the broader community that can lead to community resilience. ASDSO has a developed a "model" state dam safety program that includes public relations (ASDSO, 2007). It admits that although dam safety professionals recognize the desirability of improved public relations, they "generally make no conscious effort to reach out to the public through a well-planned effort" (p. 41). Communicating with the public, according to ASDSO, includes promoting awareness of the dam safety program, including awareness among elected officials, state and federal organizations, and the regulated community. Effective programs involve the public in permitting processes if necessary and develop "a public relations contingency/emergency plan in case of incident" (ASDSO, 2007).

Such a "public relations" approach is a good first of many necessary steps in the process of enhancing community resilience. Next steps include embracing the notion of regulator and owner engagement and collaboration with public officials and the broader public to avoid or reduce the effects of a dam failure. Disasters may sometimes be unavoidable, but community-appropriate collaboration in planning of land use and development, public safety and health, economic growth, protection of the environment, and geopolitical stability (e.g., consistency in decision criteria and community priorities related to time and space) can contribute to decision making that mitigates and potentially avoids major disasters and supports effective recovery if disasters do occur (see, e.g., Mileti, 1999).

DAM AND LEVEE SAFETY GOVERNANCE

The United Nations European and Social Commission for Asia and the Pacific defined governance as "the process of decision-making and the process by which decisions are implemented (or not implemented)." This definition can be applied in the corporate, international, national, and local contexts by formal and informal actors and through structures for decision making (UNESCAP, 2012). Governing structures reflect the nature of

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governance for dam and levee safety, in which shared authorities and processes involve both governmental and nongovernmental entities.

Governance is a key driver of dam and levee safety. How decisions are made and implemented control the level of risk that community members and stakeholders knowingly or unknowingly assume. The United States manages its waterways and water resources through a complex web of regulatory systems which sometimes overlap or leave gaps in management (see Box 3.4). Governance is made more challenging by variability in weather and climate around the country. Further complicating management of waterways is the fact that the country operates primarily under the system of riparian doctrine[11] in the East and primarily under prior appropriation doctrine[12] in the West (California operates under both doctrines). The growing influence and involvement of the private sector in water resources policy and investments also add complexity. If changes in dam and levee safety are to be made to facilitate increased regional and community resilience, governance systems will have to accommodate and facilitate those changes.

Generally speaking, most non-federally owned dams are regulated by the states. Most of the high-hazard dams listed in the NID are under the jurisdiction of the states, but state dam safety programs vary widely. States define their own regulatory jurisdiction (e.g., the height and volume of dams to be regulated), but statutes vary from state to state. Even the best programs are struggling to develop EAPs and keep up with recommended inspection frequencies. Almost all states lack sufficient funds to rehabilitate or remove unsafe dams (Galloway et al., 2011).

Federal regulatory authority for nonfederal dams is limited to the roughly 2,100 dams used for hydropower projects regulated by the Federal Energy Regulatory Commission (FERC), and mine-tailings dams regulated by the Mine Safety and Health Administration. In some cases, states have jurisdiction over dams that are also regulated by a federal agency. For example, the California Division of Safety of Dams also regulates hydropower dams, but in most states hydropower projects are excluded from the states' regulatory authority. Federally owned dams are regulated not by an independent agency but according to the policies and guidance of the individual federal agencies that own the dams.

Governance of dam and levee safety programs is discussed in the next sections with respect to the principal laws that define responsibilities, the policies that define how responsibilities are met, and practices—standards and guidelines—that are in place to comply with policies in place to achieve "safety." Finally, the status of the governance processes

[11]Riparian doctrine states that the right to water depends on ownership of land adjacent to water. All owners have equal rights to water, and water shortages are shared among owners. See www.fws.gov/mountain-prairie/wtr/water_rights_def.htm#RIPARIAN (accessed February 7, 2012).

[12]Appropriation doctrine (developed primarily for arid regions) awards water rights to the earliest appropriator for beneficial use of water from a stream. See www.fws.gov/mountain-prairie/wtr/water_rights_def.htm#APPROPRIATION (accessed February 7, 2012).

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BOX 3.4
Complexity in River Basin Management

The following statement is extracted from *Managing and Transforming Water Conflicts* (Delli Priscoli and Wolf, 2009, p. 135), in which the authors describe the types of river basin organizations that exist or have existed in North America and around the world. It is indicative of the political framework that has shaped dam and levee safety governance.

> The United States of America is a federal system. The states are sovereign entities and they have control over water resources. Like other large countries in the world, river basin operations and organizations revolve first around the alignment of powers among these sovereign entities, which rarely fit river boundaries. Second, they revolve around the exercise of bureaucratic power within the federal and state governments. Multiple agencies work with water usually within their own mandates and sector.
>
> However, there are major federal interests affecting water distribution and use. Beyond interstate commerce, federal control over water has been established in a variety of areas, such as for emergencies, flood control, irrigation, public health, environmental issues, and fish and wildlife. Many of these interests have been institutionalized in numerous federal agencies, which present a formidable coordination task. Complex formulas for the mix of federal and state money in water resources development have evolved for different project purposes and water uses, such as flood control, navigation, recreation, water supply for irrigation, and hydroelectric power.

is examined as it may be related to regional and community resilience. Governance with respect to legal liability will not be discussed in this chapter, but the committee recognizes how influential liability concerns can be with respect to dam and levee safety programs and decision making (see Box 3.5).

The Legal and Policy Framework

Numerous federal committees and professional associations in the United States have missions that include shaping dam safety policy and identifying and disseminating best practices. There is fragmentation of authority and responsibility across federal agencies and among states and private dam owners. These organizations often send mixed or incomplete messages to local and state programs that find themselves with too many responsibilities and too few resources. There are uniform federal guidelines, but these are not mandatory when most dams are state regulated. State laws and authorities vary greatly. The National Dam Safety Program (NDSP) facilitates collaboration among federal agencies, states, and

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Dam and Levee Safety and Community Resilience: A Vision for Future Practice

BOX 3.5
Liability and Safety

Liability for flood damages resulting from dam and levee failure is an important consideration in decision making related to dam and levee safety. According to Edward A. Thomas, author of a paper on liability for damage due to the failure of flood control infrastructure for the Association of State Floodplain Managers, "strict liability for damage caused by the release of water from a water control facility is the general rule of law in the United States" (Thomas, 2006). Strict liability means that any financial loss due to the failure of a water control facility as a result of inadequacies in design, construction, operation, or maintenance will be subject to compensation by the owner or operator.[a] In determining legal liability, the argument often revolves around the analysis of negligence of reasonable care that "either prevent[s] or minimize[s] risks of an accident or the resulting injuries" (Binder, 2002).

Exposure to liability is a strong incentive for safety programs to limit risk. According to Jon A. Kusler, managing exposure to liability includes giving due consideration to reducing residual risk of flooding due to storm events that exceed the design parameters of dams and levees (Kusler, 2008). Kusler also notes other ways of reducing potential liability, including incorporating wide safety factors in the design of dams and levees, informing local governments and owners and occupants of property in the floodplain of risks, and taking care in dam and levee maintenance. But such considerations beg questions such as how much should safety factors be widened? Lack of quantification and design standards may expose safety professionals to unjust liabilities and compel them to make overly conservative and costly decisions, or to take no action at all if the cost is too great.

[a]In some cases, awards for damages can run to hundreds of millions of dollars, as occurred in California when Central Valley levees failed catastrophically (see Paterno v. State, 113 Cal. App. 4th 998,(2003) *review denied,* March 17, 2004).

owners, and provides a means of supporting research and development, training, and grants, but it does not mandate uniform standards.

States also are the primary regulators of levees, often through local or regional entities such as levee boards, water boards, and private owners. There is no national levee safety program to allow collaboration and unification of levee safety standards, authorities, or management. The regulatory structure for levees is growing stronger with increased emphasis by federal agencies, but state programs remain nonexistent, fragmented, or dependent on local levee boards or local governments for management. They generally lack authority to enforce needed zoning or land-use management to control development in floodplains.

All states but one have formal dam safety programs tied to federal guidelines (Alabama does not have a dam safety program). Some state dam safety initiatives predate the 1979 national dam safety initiatives. The California State Dam Safety Program was established in 1929 (FEMA, 2004c). Ohio first enacted dam safety laws in 1963, requiring construction

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permits for new dams.[13] Ohio's law was revised in 1969 to require periodic inspection of dams, and the revised law included levees.

Professional associations have a role in assisting strategy development that could ultimately create an environment more conducive to enhancing community resilience. The Association of State Floodplain Managers (ASFPM)[14] and the National Association of Flood & Stormwater Management Agencies (NAFSMA),[15] for example, are both national-level nongovernment organizations that examine floodplain issues such as levee management and safety. Both have roles in policy development, training, and professional certification.

Dam and levee safety program governance in the United States is shaped by laws, policies, and practice, and is similar to the governance that has evolved for emergency response in the United States. Most of the responsibility for governance is in the hands of local and state governments. Separate and different authorities exist at each level. Dam and levee safety governance in other countries often follows a top-down model. The complexities of multiple layers of government, private owners and operators, multiple supporting agencies at each level, and many interdependencies result from legislation that prescribes how policy will be implemented.

Dam owners are ultimately responsible for dam safety and thus are the focus of effective programs and measures for safety. About 5 percent of the dams listed in the NID are owned or regulated by the federal government (FEMA, 2009). Most dams are owned privately or by the states. Organizations such as ASDSO provide a forum for cooperation and collaboration and in many respects have knitted state programs together.

The policy frameworks for dams and levees are discussed in more detail below.

Dam Safety Laws and Policies: Historical Setting, Organizational Roles, Guidance, and Standards

Past program emphasis has been on the physical safety and security of dam infrastructure; only secondary emphasis has been given to downstream issues or communities. The principal laws and policies that shape the governance of dam safety in the United States are provided in a simplified chronologic list in Appendix C as Table C.1. Many of the laws have been amended, and programs for flood management established in them have been reauthorized over the years. This has resulted in a complex, layered, and interwoven set of legal guidelines for dam safety. The laws and their relevant implementation policies have

[13] See www.dnr.state.oh.us/tabid/3322/default.aspx.

[14] ASFPM is an organization of professionals at all levels of government and the private and public sectors who are involved in floodplain management, the NFIP, and hazard mitigation, preparedness, and recovery. The organization's mission is to promote policy and information dissemination to minimize loss and preserve beneficial use of floodplains (see www.floods.org, accessed February 8, 2012).

[15] NAFSMA is an organization of public agencies that advocate for stormwater and floodwater management policy in the interest of public-service functions of its members (see www.nafsma.org, accessed February 8, 2012).

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spawned a variety of initiatives and technical guidance at different levels of government and in other organizations established to facilitate dam operation and maintenance.

In 1979, President Carter signed Executive Order 12148, creating FEMA. Also in 1979, the Ad Hoc Committee on Dam Safety (1979) released the first federal dam safety guidelines for federally owned dams. The guidelines were management oriented, not technical, and remain the basic principles for dam safety. The first formal NDSP was authorized in 1986 as part of the Water Resources Development Act[16] and created the NID, a first National Dam Safety Review Board (NDSRB), and provided for assistance to states.

In 1996, the National Dam Safety Program Act[17] was passed, It placed the NDSP under the director of FEMA and expanded the NDSRB to advise the director. The director was given no regulatory authority over dam safety but was charged with "encouraging the establishment and maintenance of effective federal and state programs, policies and guidelines"[18] National security considerations were added to the legal framework in 2002, and the program was reauthorized again in 2006.[19] Since 1996, the Interagency Committee on Dam Safety (ICODS)[20] has generated and released a series of guidance documents in an attempt to provide a uniform and consistent dam safety framework for federal, state, and private dam owners and regulators. The guidance, however, is not mandatory.

The nation has evolved from total dependence on dam owners to demonstrate "due diligence" with respect to dam safety in the first half of the 20th century, to the development of guidelines and regulations for the safety of federal dams in midcentury, and to guidance to encourage best practices among the states (as owners and regulators) and private owners by the end of the century. In the 21st century, dam safety remains a distributed responsibility of many agencies and owners. FEMA has oversight but no regulatory authority for implementing safety. In most cases, nonfederal owners are responsible for safety.

Table 3.2 highlights federal agencies that have responsibilities related to the safety of dams they own or regulate in the United States. As already stated, FEMA has oversight of the NDSP and provides guidelines that are the foundation of dam safety policy but has no management or regulatory authority over dam owners or operators. That responsibility is vested in individual federal agencies that construct, own, operate, and regulate dams under laws and policies as discussed above. Dams not expressly the responsibility of a federal agency—the majority in the NID—are regulated by the states. Individual agencies and the states supplement legislation and policies to reflect state management structures and financial responsibilities.

[16]See www.fws.gov/policy/361fw1.html.

[17]The National Dam Safety Act was passed as part of the Water Resources Development Act of 1996. See epw.senate.gov/dam.pdf.

[18]See epw.senate.gov/dam.pdf.

[19]See www.fws.gov/policy/361fw1.html.

[20]ICODS, established in 1980, is chaired by FEMA to serve as a forum to coordinate federal activities related to dam safety and security. See www.fema.gov/plan/prevent/damfailure/partners.shtm (accessed February 7, 2012).

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TABLE 3.2 Roles of Federal Agencies in Dam Safety

Agency	Primary Roles	Dams Under Jurisdiction
Federal Emergency Management Agency	Lead agency for National Dam Safety Program; chairs National Dam Safety Review Board and Interagency Committee on Dam Safety	Does not own any dams
U.S. Department of Agriculture (USDA)	Owns or regulates dams; supports private owners with planning, design, finance, and construction	More than one-third of dams in National Inventory of Dams (NID) are associated with USDA
Department of Defense (DOD)	Plans, designs, finances, constructs, owns, operates, and permits dams; limited to military lands with exception of USACE civil works programs	DOD has a total of 267 dams under its jurisdiction on military lands
U.S. Army Corps of Engineers	Plans, designs, constructs, operates, and regulates dams; permits and inspects dams	Jurisdiction over USACE dams, dams constructed by USACE but operated by others, and other flood control dams subject to federal regulation; 631 dams in the NID are associated with USACE
Department of the Interior	Plans, designs, constructs, operates, and maintains dams	About 2,000 dams in the NID under five bureaus
Department of Labor	Regulates safety- and health-related aspects of miners	About 1,400 dams under Mine Safety and Health Administration
Federal Energy Regulatory Commission	Issues licenses for, provides inspections of, and regulates nonfederal dams with hydroelectric capability	2,530 dams in the NID affecting navigable waters
Tennessee Valley Authority	Plans, designs, constructs, operates, and maintains dams	49 dams in Tennessee River Valley

SOURCE: FEMA (2009).

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Table 3.3 summarizes dam safety governance, guidance, and standards. The principal governance documents are provided in FEMA federal guidelines. Other guidance and standards, mostly technical, come from FERC, USACE, and the Bureau of Reclamation. A single technical specification (e.g., using the probable maximum flood for spillway design) can dominate design considerations.

There have been substantial improvements in dam safety practice, but in general, practice fails to take a systems approach in its efforts. For example, the development of the Potential Failure Mode Analysis (PFMA) process (FERC, 2005) requires a deliberate effort to systematically identify and document all potential modes of failure of a dam from all sources. PFMA is used by the Bureau of Reclamation, USACE, FERC, and others in the dam safety community, however, PFMA, as currently applied, lacks a systematic basis for relating the infrastructure-based analyses to the larger river system or to the communities at risk. Thus the utility of PFMA in terms of risk-informed decision making is limited. The PFMA process will likely continue to be used, but the practice could be improved if it evolved to recognize and address epistemic sources of uncertainty, became more detailed to address modes of failure unique to different initiating events (e.g., earthquakes), and was executed using a systems analysis approach in which interactions and interdependencies between system elements are evaluated.

Another substantial evolution in guidance provided at the federal level has been the development of a risk assessment framework for dams. It has come about particularly in a collaborative effort between USACE, the Bureau of Reclamation, and FERC. Figure 3.4 outlines the emerging Federal Dam Safety Portfolio Risk Management Process (USACE, 2011b). This process employs the Dam Safety Action Classification (DSAC), a categorization scheme ranging from "Urgent and Compelling" to "Normal" for safety-related actions. Interim risk reduction measures (IRRMs) are formulated and undertaken for dams not considered tolerably safe until more permanent remedial measures are implemented. The authority for applying risk has existed for some time (USACE, 2006); it is becoming a reality. Application of risk measures will be important in moving from deterministic standards-based approaches to estimating and applying resilience measures that include both the probability and consequence components of risk assessment.

Levee Safety Laws and Policies: Historical Setting, Organizational Roles, Guidance, and Standards

The principal laws and policies that shape the governance of levee safety in the United States are provided in a simplified chronological list in Appendix C as Table C.2. Just as for laws that define dam safety policy, many laws related to levee safety have been amended multiple times. Because the legal and policy setting for levees is less mature than that for dams, there is less definitive legislation, policy, and technical and management guidance.

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TABLE 3.3 Dam Safety Governance-Related Guidelines and Standards

Responsible Agency	Publication	Scope
Interagency Committee on Dam Safety	FEMA 93: *Federal Guidelines for Dam Safety*, (FEMA, 2004c; reprinted from 1979)	Federal agency owners; addresses management practices; no technical standards
Federal Emergency Management Agency	Federal guidelines for dam safety: FEMA 64: *Emergency Action Planning for Dam Owners* (FEMA, 1998) FEMA 333: *Hazard Potential Classification System for Dams* (FEMA, 2004b) FEMA 65: *Earthquake Analysis and Design of Dams* (FEMA, 2005) FEMA 94: *Selecting and Accommodating Inflow Design Floods for Dams* (FEMA, 2004d) FEMA 148: *Glossary of Terms* (FEMA, 2004a)	Technical guidelines that augment FEMA 93 and create a big-picture framework for state dam safety programs
Federal Energy Regulatory Commission	Chapter 14: Engineering Guidelines updated July 1, 2005 (FERC, 2005)	Dam Safety Performance Monitoring Program and Potential Failure Modes Analysis
U.S. Army Corps of Engineers	ER 1100-2-1156, *Safety of Dams—Policy and Procedure* (USACE, 2011b)	New Policy on application of risk and portfolio methods to dam safety throughout USACE
Bureau of Reclamation	*Dam Safety Risk Analysis Best Practices Training Manual* (USBR, 2011a)	Summary of best practices in spectrum of technical subjects relevant to dam safety; collaborative with USACE

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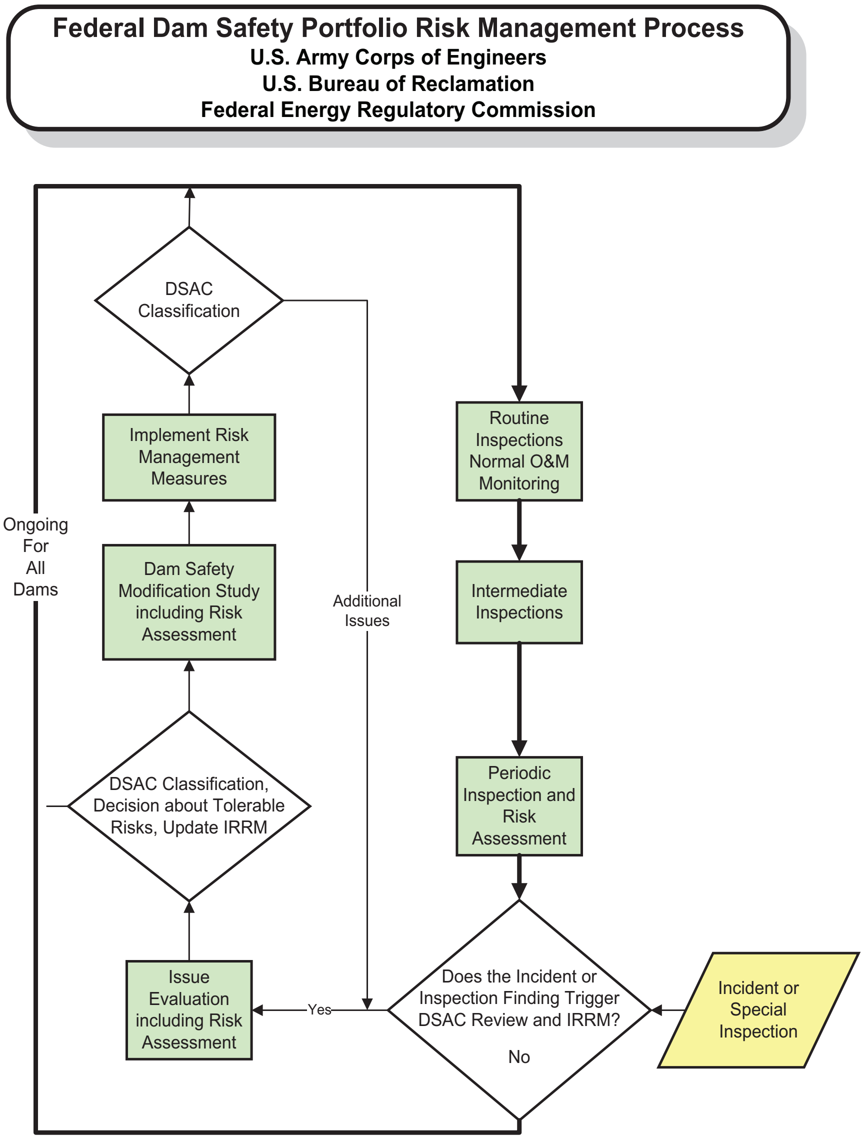

FIGURE 3.4 Schematic of emerging Federal Dam Safety Portfolio Risk Management Process. Green boxes represent routine dam safety processes executed under the federal dam safety guidelines (outer loop) or nonroutine safety processes (inner loop). For any process, "yes" indicates further effort and another decision; "no" indicates return to routine activities. Scrutiny of a potential problem (yellow diamond) triggers a nonroutine process, and a decision made regarding if and what actions are necessary, and if actions taken have been sufficient. DSAC (Dam Safety Action Classification) depicts the degree of urgency of safety-related actions. IRRMs (Interim Risk Reduction Measures) are formulated and undertaken for dams not considered tolerably safe until more permanent remediation measures are implemented. SOURCE: USACE (2011b).

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Defining legislation is emerging only recently, and is limited to the requirement to create a National Committee on Levee Safety and a proposal for a national levee safety program.

Levee safety has been a concern for most of the last century, but other than individual federal-agency programs and state-level initiatives, efforts have been ad hoc. Although intended only to be a requirement for the NFIP,[21] the NFIP 100-year flood—rather than hydrograph shape and duration—has become a de facto national standard. The 100-year water elevation now serves as a baseline for many levee applications.

The 2005 authorization of the NLD and the 2007 Water Resources Development/ National Levee Safety Act have placed levee safety in phase with where dam safety was in the 1980s.[22] These steps constitute an initial legal and policy scaffold from which levee safety can be designed and constructed into a nationally consistent and rigorous effort (given the appropriate attention and resources). It will be crucial to bring diverse community members and stakeholders together to create a uniform structure for management and technical decision making. An important development will be the application of risk assessment.[23] The NCLS (2009) has submitted a report and recommendations for policy and organization for a national levee safety program, but its recommendations remain under consideration (as of this writing).

The current Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G) are the fundamental policies that govern how federal agencies evaluate proposed water resource development projects, emphasizing national economic benefits as the primary criterion for project justification (WRC, 1983). The secretary of the Army was tasked with updating the P&G under the Water Resources Development Act (WRDA) of 2007.[24] The Obama Administration is expanding the scope of the P&G to include all federal water resources agencies.[25]

Major responsibilities in levee safety rest with FEMA and USACE and in some cases with the states. FEMA administers the NFIP, through which it defines its responsibilities related to levees, particularly regarding levee accreditation and mapping areas protected by levees. FEMA is examining the impact of levee mapping on the NFIP, initiatives such as the Map Modernization program[26] (which, among other things, establishes criteria for levee accreditation), and is examining risk-based approaches. FEMA also cochairs the National Committee on Levee Safety. USACE is responsible for the 14,700 miles of levees it has constructed, operates, and maintains, as well as levees it has constructed but are operated and maintained by others, and levees included in the Rehabilitation and Inspection

[21] See a www.fema.gov/business/nfip/.

[22] See 140.194.146.135/LeveeSafety/Documents/timeline.pdf.

[23] Some states are developing new flood hazard criteria. California, for example, has a draft standard in place for using the 200-year return-period peak flood as its design criterion for urban and urbanizing areas (CA DWR, 2012b).

[24] See www.gpo.gov/fdsys/pkg/PLAW-110publ114/content-detail.html.

[25] See www.whitehouse.gov/administration/eop/ceq/initiatives/PandG.

[26] See www.fema.gov/plan/prevent/fhm/mm_main.shtm (accessed February 8, 2012).

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Program (per Public Law 84-99).[27] The Secretary of the Army is responsible for carrying out activities of the new National Levee Safety Program Act.[28] The USACE Director of Civil Works chairs the NCLS tasked with developing policy and recommendations for a National Levee Safety Program under that act. Their report, delivered in January 2009 remains under review by the Office of Management and Budget and, as of the writing of this report, the recommendations remain unaddressed.[29] Other federal agencies, including the Department of Interior (DOI) and U.S. Department of Agriculture, have roles in levee safety. The DOI Bureau of Reclamation manages some levees associated with water supply and flood control projects and oversees levees associated with some irrigation projects that are owned and operated by others. The USDA Natural Resources Conservation Service designs levees to provide protection to support agricultural use of land (ILPRC, 2006).

Table 3.4 summarizes guidance and standards for levee safety. As for dam-related guidance, these are technical in nature and support governance by informing decisions. An important technical issue affecting governance is standards related to the extent that hazards affect design and operation. For example, USACE standards for levee design were once based on the Standard Project Flood (SPF), a flood that can be expected from the most severe combination of meteorologic and hydrologic conditions considered reasonably characteristic of the region. The SPF was often considered to be equivalent to a 300-year (or more) return-period event when plotted on an extrapolated flood-frequency curve for the location (USACE, 1965, 2006). With the acceptance of a 100-year peak flood as the standard in accordance with the NFIP, the design criterion was effectively changed (e.g., from a 300-year to a 100-year return period). More recently, USACE has been moving to risk-based design, creating a new design paradigm for the United States (USACE, 2011b). FEMA is considering incorporating risk-based standards into the NFIP; this would constitute a major shift in design guidance and standards for levees (see Box 3.6).

Given the lack of national policy, guidance, or standards for states, NFIP criteria influence management decisions via local government or community initiatives established to qualify for flood insurance. But as stated earlier, few states keep lists of levees within their borders, and about half the states have no formal authority or program at the state level for levee safety or inspection programs (as of 2006).[30] Fewer than one-third of states have even modest safety programs, whose implementation is often delegated to local authorities or programs, and only about 20 percent of the states have relatively comprehensive authorities and programs. Management of levees in some states is through levee boards or similar organizations. Levee boards in Louisiana, for example, are managed through the Department of Transportation and Development and consist of community members appointed

[27] See www.saj.usace.army.mil/Divisions/Operations/Branches/EmergencyMgt/programs_RIP.htm.
[28] See uscode.house.gov/download/pls/33C46.txt.
[29] See www.leveesafety.org/faq_committee.cfm.
[30] M. Ogden, ASDSO, personal communication, September 7, 2011.

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TABLE 3.4 Levee-Safety Governance-Related Guidance and Standards

Date	Responsible Organization	Publication
October 2010	U.S. Army Corps of Engineers (USACE)	Proceedings of the Workshop, "Exploration of Tolerable Risk Guidelines for the USACE Levee Safety Program," Institute for Water Resources Report 10-R-8
April 2009	USACE	ETL 1110-2-571, *Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures*
October 2008	State of California	*Draft Interim Levee Design Criteria for Urban and Urbanizing Areas (200-year protection by 2015)*
April 2000	USACE	EM 1110-2-1913, *Design and Construction of Levees*
May 2005	USACE	ETL 1110-2-569, *Design Guidance for Levee Underseepage*
August 2010	USACE	EC 1110-2-6067, *USACE Process for the NFIP Levee System Evaluation*
August 2005	Federal Emergency Management Agency (FEMA) Procedure Memorandum 34	Procedure Memorandum 34, *Interim Guidelines for Studies Including Levees.* Requires Certification Data on Levees
July 2008	FEMA Procedure Memorandum 43	Procedure Memorandum 43, *Guidelines for Identifying Provisionally Accredited Levees.* Removes levee from NFIP if not accredited and allows provisional accreditation for 2 years
October 2002	44 CFR § 65.10	Section 65.10 of National Flood Insurance Program Regulations: FEMA guidance on mapping areas protected by levee systems (not risk based)

by the governor. Louisiana has a state association of levee boards, ostensibly to coordinate activities of all Louisiana levee boards.[31] Of formal state levee-safety programs, California's, in its Department of Water Resources, appears to be the most advanced (see Box 3.7).

[31]See www.albl.org (accessed February 8, 2012).

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BOX 3.6
Uncertainty in Hazard Characterization

The uncertainty in hazard characterization is increasingly recognized in applying risk-based procedures (and setting policy related to their use). Calculations of the frequency of flood events, for example, are improved with larger, accurate, and complete historical-event databases. The greater the number and accuracy of events in the database, the smaller the uncertainty in the estimate of the frequency of future events. This can be demonstrated through the calculation of return-period frequency of hurricanes in the Gulf of Mexico.

Hurricane return-period calculations have long been based on the atmospheric pressure at the hurricane center (its central pressure). Table 1 illustrates the change in estimated return period for a storm like Katrina, given the size of the historical-event database. The return period of a hurricane with a central pressure and maximum wind speeds similar to those of Hurricane Katrina would have been calculated at 900 years by using the historical database as of 1959, but at only at 98 years on the basis of the historical record as of 2005 (Irish et al., 2008). In addition, the use of central pressure alone, as was previously done, is not adequate to characterize the surge generation potential of a hurricane. It is necessary to consider both central pressure (storm intensity) and radius to maximum winds (physical size) of the storm to represent its ability to generate storm surge. Therefore, using the Saffir-Simpson Scale (representing the intensity of sustained winds) as a basis of characterizing return period relevant to surge levels is inadequate.

In the 1960s, the levee systems for hurricane protection around New Orleans were designed according to the USACE criteria that, at the time, were thought to accommodate a 200- to 300-year event. The uncertainty analysis conducted by IPET (2009) as a component of the risk assessment of the levee and floodwall systems in place during Katrina estimated that the system had a mean failure period of 40–50 years (caused by catastrophic breaching, given the 2005 knowledge base of hurricane hazards in the gulf).

TABLE 1 Variability of Return Period of Hurricane Hazard in Gulf of Mexico

	Publication (Year) and Period of Record		
Meteorological Parameter	U.S. Weather Bureau Tech Report 33 (1959) 1900–1956	National Weather Service Tech Report 23 (1979) 1900–1975	National Oceanic and Atmospheric Administration and National Climatic Data Center Preliminary Analysis (2006) 1900–2005
100-year central pressure index (millibars)	934.6	926.2	901.7
100-year peripheral pressure (millibars)	1,013.2	1,008.1	1,007.9
Return period for a storm of Hurricane Katrina intensity (905 mb) (years)	900	285	98

SOURCE: IPET, (2007a, 2009).

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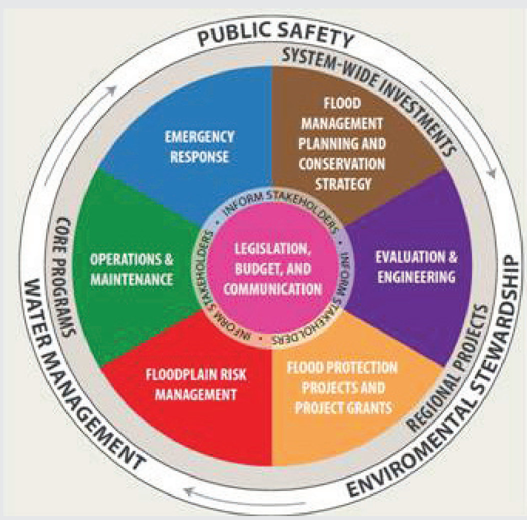
BOX 3.7
Levee Safety in California

California has a highly developed levee safety program. The Division of Water Management in the California Department of Water Resources (DWR) was established in 1977 and is divided into five offices responsible for forecasting, integrated environmental stewardship and flood management, design and construction of flood control projects, rehabilitation of California system levees, and operation and maintenance of federally constructed flood control structures.[a] The California FloodSAFE initiative, formulated in 2007, is aimed at more effective floodplain management, risk reduction, and development of a comprehensive, systemwide flood management plan for the Central Valley of California.

A major tenet of the FloodSAFE initiative is to require that building codes include flood damage-reduction measures for the estimated 200-year floodplain.[b] This applies to areas protected by facilities of the Central Valley Flood Protection Plan where flood depths exceed 3 ft for the 200-year flood event (0.5 percent annual chance of flood). Code updates are planned in cycles and include such measures as requiring flood evacuation locations to be above the 200-year water-surface elevation, and requiring that flood vents be designed to reduce the potential for structural collapse (by reducing hydrostatic differential on walls).[c] FloodSAFE also includes preparation of 200-year flood inundation-area maps and flood information for owners and residents. The program is the focal point of the Division of Flood Management in the DWR. Resources in the DWR have been divided into seven "functional areas" as depicted in the figure to prepare for implementation of the program. Limited financial resources will be the major challenge for full implementation of FloodSAFE.



Organization and alignment of DWR resources to prepare for the implementation of the DWR FloodSAFE initiative. SOURCE: CA DWR (2012a).

[a]See www.water.ca.gov/floodmgmt/ (accessed March 8, 2012).
[b]See www.ca.gov/floodsafe/ (accessed March 8, 2012).
[c]See www.water.ca.gov/BuildingCod (accessed March 8, 2012).

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CHAPTER FOUR

Vision and Conceptual Framework for Resilience-Focused Engagement

The committee envisions a future in which dam and levee safety professionals (e.g., owners, operators, and regulators) and the broader public are active, collaborative, and mutually committed participants in efforts to enhance public safety and community resilience. This vision includes mitigation and emergency preparedness efforts that are the traditional focus of dam and levee safety professionals; more importantly, it calls for dam and levee safety professionals to understand and become more involved in their communities. By broadly engaging with other community members and stakeholders, these professionals can identify their individual and common needs and the actions necessary to meet those needs, and increase resilience to dam and levee infrastructure failure. Such interaction will require participation in new or existing collaborative processes designed to meet the mutual needs of and provide benefits to all the community (including themselves) as part of the working fabric of a community.

Such a vision is achievable when all dam and levee professionals, other community members, and stakeholders more broadly recognize the mutual benefits and increased social capital to be gained through participation in processes that enhance community resilience. The vision is achievable only through an expansion of traditional dam and levee safety practice coupled with changes on the part of policy makers and the broader public to recognize the benefits of dam and levee infrastructure. This kind of evolution cannot occur rapidly; it will require incremental changes and improvements in safety program processes.

Advances in dam safety practices over the last four decades provide an excellent foundation for a community engagement approach to greater resilience. This chapter defines a vision and framework for dam and levee safety professionals to become engaged participants in enhancing the resilience of their communities.

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DAM AND LEVEE PROFESSIONALS AS PART OF THE LARGER COMMUNITY

A previous National Research Council report (NRC, 2011a) concluded that a framework for increasing community resilience will likely be more successful if designed by representatives of the entire community. Table 2.1 lists the elements of the community with a stake in dam and levee performance, and therefore the elements to be engaged. However, the committee observes that dam and levee professionals often operate their programs independently of other community functions and fail to understand the value of social engagement or social capital for their programs. Until they recognize the benefits of community engagement, improvements in resilience to dam and levee failure will be minimal. It is essential that dam and levee professionals engage with the broader community to identify shared goals and resources, and to collaboratively develop strategies and processes to support resilience. Simply put, a new dam and levee safety norm is needed. This means moving beyond the boundaries of regulatory compliance. Box 4.1 provides an example of how some in the dam and levee profession have begun the evolution toward new operational norms. The committee expects such norms will become community expectations of its dam and levee professionals.

New Societal Expectations

The ability of industry, government, and infrastructure owners to meet evolving societal expectations can be demonstrated by the response to recent demands for greater sustainability and environmental stewardship. For example, the U.S. General Services Administration now requires Leadership in Energy and Environmental Design (LEED) certification for all new or substantially renovated federal buildings,[1] and other groups are voluntarily seeking LEED certification in new construction. The dam community can be similarly responsive to societal expectations. Public-utility districts in Washington state, for example, have engaged with state and federal fisheries agencies, Native American groups, and state and federal wildlife agencies to develop 50-year hydropower habitat conservation plans to protect local fish populations through environmental restoration, fish bypass and spill systems, and offsite hatcheries.[2] The goal is to ensure that sustainable hydropower will be available without compromising fish resources. Not long ago, few dam owners placed great importance on wildlife protection. Now, wildlife protection is a legal requirement, a normal part of engineering practice, and often publicly touted by dam owners as evidence of good community citizenship and environmental stewardship.

As communities become more aware of the benefits of creating, sustaining, and increasing community resilience, and more aware of the benefits and risks associated with

[1]See www.gsa.gov/portal/content/197325 (accessed November 30, 2011).
[2]See www.chelanpud.org/habitat-conservation-plans.html (accessed November 30, 2011).

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BOX 4.1
Interview with Robert A. Turner, Jr., Regional Director, Southeast Louisiana Flood Protection Authority–East

Shirley Laska, of the University of New Orleans Center for Hazards Assessment, Response and Technology, conducted an interview with Robert A. Turner, Jr., regional director of the Southeast Louisiana Flood Protection Authority–East (SLFPAE)[a] on November 1, 2011, to learn about his approach to flood risk reduction.

According to its website, the mission of the SLFPAE "is to ensure the physical and operational integrity of the regional flood risk management system, and to work with local, regional, state, and federal partners to plan, design, and construct projects that will reduce the probability and risk of flooding for the residents within our jurisdiction." The SLFPAE process of levee inspection and information dissemination has been evolving to make information more accessible to residents. Levee inspections have become more rigorous, and the levee district plans to migrate from a paper to a digital system, creating a levee information management system. The district plans eventually to launch a user-friendly website that allows more sophisticated oversight.

According to Turner, part of the authority's strategic plan is to "actively communicate to the public the risks that exist with current and proposed flood protection strategies." Turner described SLFPAE stakeholders as having "a vested interest in levees . . . people who live and work and own businesses in the areas. . . . All of the taxpayers have a vested interest in what happens to our levees."

Turner sees that he has a role in land-use planning by influencing change, although he admits that he does not have the authority to make changes. "We can give decision makers the benefit of our knowledge, for example about risk [and] consequences. Our role is more about trying to inform those decision makers of the appropriateness of their decisions."

Turner has been the regional director of SLFPAE since 2007 and was executive director of the Lake Borgne Basin Levee District from 2001 to 2007. He was asked how his viewpoint about risk reduction has changed since Hurricane Katrina in 2005. Turner said that before Hurricane Katrina, "I saw myself as leading the charge to build levees better. My views on that have changed. I now believe in a more integrated approach to deal with flood safety. . . . Smarter is to try to do the best we can with money available for structures, but that effort has to be integrated with all of the other things. I never thought that was the case, but now it is so obvious. Since Katrina, there is no other way to think about it. Levees can't provide all of the protection. For example, if we can't address coastal issues—coastal restoration—then the levee system will degrade. . . . [The] only way to keep risk from rising is to work on the other things we can affect, i.e., people's behavior. I never thought I would have to say: 'buy flood insurance.'"

[a]See www.slfpae.com (accessed February 27, 2012).

dam and levee infrastructure, more social and legal pressures will be placed on dam and levee owners to participate in and inform efforts to enhance community resilience. When the owners work with their communities to identify shared community risks, resources, and appropriate disaster mitigation, preparation, response, and recovery measures, they have the opportunity to help shape societal expectations and solutions. As the nation moves forward

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Dam and Levee Safety and Community Resilience: A Vision for Future Practice

to develop and implement a national resilience strategy (e.g., NRC, 2012), there is motivation for dam and levee owners to engage early and comprehensively in community efforts.

Dam and levee owners (and many others) may not be knowledgeable generally of the social capital basis for community resilience (e.g., the role of community decision making in resilience). Because metrics for measuring success of resilience-enhancing efforts are not available, many owners may choose to wait and see what new requirements and metrics will evolve with respect to resilience, especially as national efforts to develop a resilience strategy continue. However, societal demands for community resilience-related action will likely precede the implementation of a national strategy. Dam and levee owners can take advantage of lessons learned from tackling some dam safety and environmental issues and developing emergency action plans (EAPs) in collaboration with other community members.

Moving Beyond Regulatory Compliance

The dam safety community has evolved substantially toward stronger regulatory and owner (public and private) dam safety programs. Generally, however, regulatory compliance as defined in legislative mandates and safety standards remains the driving motivator for dam safety regulators and private and public dam owners. Regulations are established to achieve minimum safety levels for built infrastructure, but compliance alone does not necessarily ensure reliability and safety of dams and levees. Failures occur, sometimes for reasons not considered in the original design or because of unforeseen circumstances.

Just as regulatory compliance alone does not ensure dam and levee safety, compliance alone may not be consistent with owner interests (e.g., system efficiency, operational reliability, and profitability), with good stewardship of community resources (e.g., water and the environment), or with reduction in owner liability. Demonstrating compliance with regulations does not necessarily protect an owner from litigation if infrastructure failure results in damages or loss of life. And it does not build the social capital discussed in Chapter 2 that can result in desired community or economic outcomes. Even in light of those limitations, it is easy to anticipate the dam safety community's reluctance to adopt practices that move beyond regulatory compliance in the interest of increasing community resilience. The benefits of progressive actions need to be identified and balanced against cost, liability, and other concerns that become institutional impediments.

Given the lack of federal or state regulatory structure with respect to levee safety, meeting even minimum safety standards is difficult for the levee professional community. In such a situation, it is even more important for levee professionals, especially levee owners, to broadly consider costs and benefits to all affected by decisions related to levee infrastructure design, construction, and maintenance.

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Incentives for Dam and Levee Professionals

The committee recognizes that a commitment by dam and levee professionals (and all stakeholders for that matter) to processes that build community resilience is a major undertaking, especially if resilience-related concepts and practices are unfamiliar. The benefits of and incentives for active participation are, admittedly, not readily apparent or quantified. Nonetheless, many public and private organizations are familiar with the merit of participating in pursuits that build goodwill in the community (e.g., community charities and buying and hiring locally) or that would be in the category of being good "corporate citizens" (in the case of private organizations). Although it is difficult to quantify, it is easy to recognize the value to dam and levee safety professionals and the broader community of having the ability to avoid, or recover as soon as possible from, the effects of a disaster such as might result from dam or levee failure (e.g., Rexford, Idaho, after the Teton Dam failure in 1976 or New Orleans after the levee failures that occurred during Hurricane Katrina in 2005). With this in mind, the committee discusses here some benefits of and incentives for engaging in collaborative processes to build resilient communities.

Initial incentives for private and public dam and levee owners to collaborate in resilience-enhancing processes may include increased profitability, decreased liability, increased trust in and of the broader community, goodwill, and recognition as good community citizens. For dam and levee safety regulators, whose principal responsibility is public safety, engaging in community resilience-building processes is an opportunity to support the public-safety mandate. As dam and levee owners mature in their roles as participants in community resilience-building efforts, the opportunity to contribute to and influence specific community planning and decision making (e.g., with respect to emergency management and recovery) and broader decision making (e.g., for land-use planning) can be further incentives. Building the case for participating in community resilience efforts and moving them into the mainstream of dam and levee safety practice may be difficult, but it presents an opportunity for federal agencies and professional associations involved in dam and levee safety. Efforts will be most effective if initiated from within the profession, possibly with the assistance of federal agencies.

Benefits of Community Engagement

Collaborative networks form because those engaged in collaboration recognize that individual and collective goals are more likely to be met through collaborative, rather than individual, efforts (NRC, 2011a). The need for partnering and collaboration is recognized by the federal government (see, e.g., DHS, 2009) and in the literature of many fields, including collaborative management (e.g., McGuire, 2006), emergency management (e.g., Waugh and Streib, 2006), public health (e.g., Butterfoss, 2007), and public administration

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(e.g., Vigoda, 2002). The idea of collaboration is not new in the world of flood management. The Netherlands, for example, recommended the development of a European Union flood protection program with a goal of promoting collaboration among neighboring countries to examine the risk and appropriate measures against flood surges. Within the Netherlands itself, a collaborative approach to risk identification and management is being adopted (MTPWWM, 2008). In the examples above, collaboration is a means of managing complex systems with numerous interdependences that could not adequately be understood by a single entity or person. Collaboration is a means of making a complex network stronger, more efficient, and more resilient.

In many respects, resilience is a somewhat intangible goal with few direct metrics available for measuring success (short of observed responses to actual dam or levee failure). Thus, dam and levee owners and engineers may find it difficult to embrace the benefits of the many seemingly intangible steps needed to increase resilience. The intermediate steps—for example, building trusted collaborative networks—are vital and beneficial milestones toward identifying mutual needs and taking required actions to meet them. Box 4.2 illustrates some benefits derived from resilience-building efforts for dam and levee owners. Many of them are associated with corresponding benefits to the broader community (some listed in the table). They are all examples that will facilitate risk awareness, risk reduction, and increased resilience for communities.

Many other benefits may exist, and still others may be community specific. Roles for the federal government may be to help identify and communicate the general benefits of resilience-focused collaboration, and to help identify and communicate benefits specific to individual communities. Ultimately, the federal government could channel relevant information, examples, and data from the state and local levels that represent best practices and results and could serve as examples and incentives.

Engagement and Selection of Processes

Effectively engaging a community on issues related to community resilience involves more than making presentations to city councils, town boards, or similar community bodies. Those interactions are encouraged, can be made more robust, and be initiated more frequently to seek other forms of collaboration. Dam and levee professionals may already interact with numerous public officials, both elected and appointed (e.g., emergency management directors), but could seek out other community representatives to expand discussions. Some interactions—at least those in which federal water management professionals participate—may already employ decision-making processes such as those established in the well-known principles and guidance (P&G), *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (U.S. Water Resources Council, 1983). As such, these professionals should already be familiar with the

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BOX 4.2
Examples of Intangible Benefits of Resilience-Focused Collaboration Between Dam and Levee Safety Professionals and the Broader Community

- Consensus identification and articulation of mutual and community needs and resources to create and increase safety and resilience
- Understanding of critical factors related to community well-being (social capital) that need to be protected; greater use of local knowledge in collaborative approaches
- Development of community networks useful for increasing resilience and furthering other corporate strategies
- Increased trust among collaborators that facilitates communication and the building of social capital
- Understanding and embracing responsibilities of good community citizenship; being recognized by the community as good citizens
- Better understanding of community stakeholders; increased awareness of benefits and risks associated with dam and levee infrastructures and consequences of failure for different stakeholders
- Continual awareness of community infringement on and plans for increased development in floodplains; awareness of change in floodplain status
- Increased mitigation of risk and preparedness for potential failure; effective risk-reduction and resilience-building plans and capabilities represented in Emergency Action Plans
- Improvements in standards, regulations, enforcement, and investment
- Better understanding of community priorities that may inform decisions influencing infrastructure integrity and liability

A culture of collaborative engagement that achieves mutually beneficial dam and levee safety and community resilience

importance of specifying problems and opportunities, inventorying and forecasting conditions, formulating alternative plans, evaluating the effects of alternative plans, comparing plans, and selecting final action plans. This type of outline is scalable to all manner of decisions.

Although the ultimate goal of engagement may be to establish a formal resilience-focused collaborative process in which representatives of the local community and stakeholders more broadly are engaged, it is advisable to consider first how existing relationships could be improved, and then to expand community involvement incrementally. Tools will need to be identified, perhaps with the help of the federal government, to identify stakeholders, choose appropriate organizational vehicles for community engagement, and assist collaborative identification of desired community outcomes and the processes needed to achieve them (see Chapter 5 for more discussion).

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Resilience-focused collaborative engagement in its early phases could focus on, for example,

- identification of community members, stakeholders, and motivation for engagement;
- open sharing and accessibility of critical hazard and risk information (e.g., inundation maps, EAPs, and risk estimates);
- identifying community attributes critical for resilience;
- identifying and instituting community risk mitigation and reduction measures;
- communicating the value of risk reduction and resilience;
- identifying common and conflicting community priorities; and
- examining alternatives for reducing risk and increasing resilience with regard to community values and priorities.

As collaboration matures, focus of activity can also mature. Collaboration can address the conflicting local community and regional stakeholder interests that often arise, and address other issues such as adaptation, social learning, and adaptive management[3] processes over the long term.

Federal and state dam safety regulatory agencies and the Federal Emergency Management Agency are leaders in improving dam safety and in heightening national awareness of dam safety issues with owners, legislatures, Congress, and the public. Their focus has been on mitigating dam failure through dam inspection programs and required remediation. Regulators require EAPs and often oversee tabletop and field exercises. Where efforts to enhance community resilience are under way, dam safety regulators will have expanded responsibilities and unique roles in newly established collaborative networks. Regulatory officials are in a position to facilitate trusted relationships and collaborative efforts involving dam owners and communities, particularly in the early stages of collaboration as processes evolve. The dam safety regulator may

- facilitate discussions between the broader community and a dam owner;
- broker information—assist communities in identifying, obtaining, and interpreting information that supports, for example, emergency planning and preparedness, identification of risk-reduction alternatives, and adaptive measures against future hazardous events; and
- serve as a technical resource in community efforts by interpreting aspects of, for example, dam operations, dam-break scenarios, risk information, and risk reduction alternatives.

[3]Adaptive management refers to "a formal, systematic, and rigorous program of learning from the outcomes of management actions, accommodating change, and thereby improving management" (Holling, 1978; NRC, 2003).

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In these and other ways, dam safety regulators can play a vital role in the formative stages of establishing networks and processes that support community resilience-building efforts. Their unique relationships with dam owners provide opportunities to engage them to become positive, collaborative partners with the broader community.

Efforts at engagement and the selection of appropriate risk reduction efforts will be assisted through the development and dissemination by the federal government of tools, information, and examples of successful collaborative processes needed to establish collaborative relationships. As stated earlier, the federal government can direct such information and guidance for use by the dam and levee community.

CONCEPTUAL FRAMEWORK: EXPANDING THE MEANING AND ROLE OF DAM AND LEVEE SAFETY

The importance of community resilience is being recognized at the national level, but the path to making communities resilient has not been defined. Nonetheless, concepts are being developed and information on enhancing and assessing community resilience is increasing. Some basic principles are highlighted in Chapter 2. In light of these principles, the committee develops here a vision of how resilience with respect to dam and levee safety might be achieved, and the role of dam and levee professionals in realizing that vision.

The committee envisions a future in which the dam and levee safety community and the greater public recognize their individual and shared needs for effective infrastructure management and for developing a community capacity to mitigate, prepare for, recover from, and adapt in response to adverse local, regional, national, and global consequences of dam and levee failures. That future involves support by all of the community for collaborative processes that increase community capacity to protect itself from (often unexpected or highly uncertain) adverse events. As the nation increases its understanding and appreciation of what it takes to enhance community resilience, a paradigm shift is required specifically in the dam and levee safety community, and more generally in other elements of the broader community.

A recent NRC report concluded that private–public collaboration is an ideal and fundamental component of enhancing community disaster resilience (NRC, 2011a). The present committee draws heavily on the findings and conclusions in that report, which are based on an all-hazards approach to community resilience that presumably includes hazards associated with dams and levees. Those conclusions provide a starting point for a dam- and levee-specific framework. As recognized in the report, community resilience-enhancing efforts are community specific, community initiated, and community guided. This certainly applies to addressing the unique community risks associated with dams and levees (with recognition of the differences between dams and levees), such as the following:

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- Many dams provide lifeline societal services (e.g., water supply, irrigation, and power), which are often essential for recovery after a disaster.
- Failure of dams may not only eliminate lifeline services but have potentially catastrophic consequences for a community or region.
- Flooding due to a levee failure can linger for an extended time (as was the case for the U.S. Midwest during 2011) and compromise community recovery efforts.

A conceptual framework for incorporating concepts of collaborative community resilience into dam and levee safety programs is presented later in this chapter. The framework recognizes that in any given community there are numerous means of enhancing resilience that will benefit both dam and levee owners and the broader community. The benefits include the reduced impact of a failure if it occurs, effective and efficient community recovery and adaptation, and protection of the dam or levee owner's "brand," "bottom line," and liability. It is also expected that technical decisions made by dam and levee safety professionals will be influenced by community priorities, potentially resulting in the reduced likelihood of failure. The earlier NRC report's framework for private–public collaboration to enhance community resilience, illustrated in Figure 4.1 (NRC, 2011a), is a generic framework intended to be modified for particular community circumstances. The framework for incorporating concepts of community resilience in dam and levee safety programs requires a perspective more compatible with the responsibilities of the dam and levee safety community and its management of risk. The intermediate and end outcomes, although similar to those shown in Figure 4.1, will be more targeted.

Major Elements of a Framework for Resilience-Focused Collaboration

Figure 4.1 depicts collaborative engagement as necessarily influenced by community factors, and necessarily responsive to changes in the community over time. Participants in collaboration develop a collaborative management structure, decide and carry out its various activities that lead to community synergy and increased community resilience. A framework for the dam and levee safety community must also be responsive to the fact that communities evolve in response to a host of factors outside the realm of dam and levee safety. Political leadership will change; legislation with respect to dam and levee management may be revised; economic vitality or major sources of community income may change; populations may move in or out, causing shifts in cultural attitudes and expectations; and environmental issues may evolve, depending on land use, quality and quantity of drinking water, or environmental preservation. For these and many more reasons, modes of collaboration and processes to enhance resilience must be evaluated regularly to remain relevant and to maximize efficiency.

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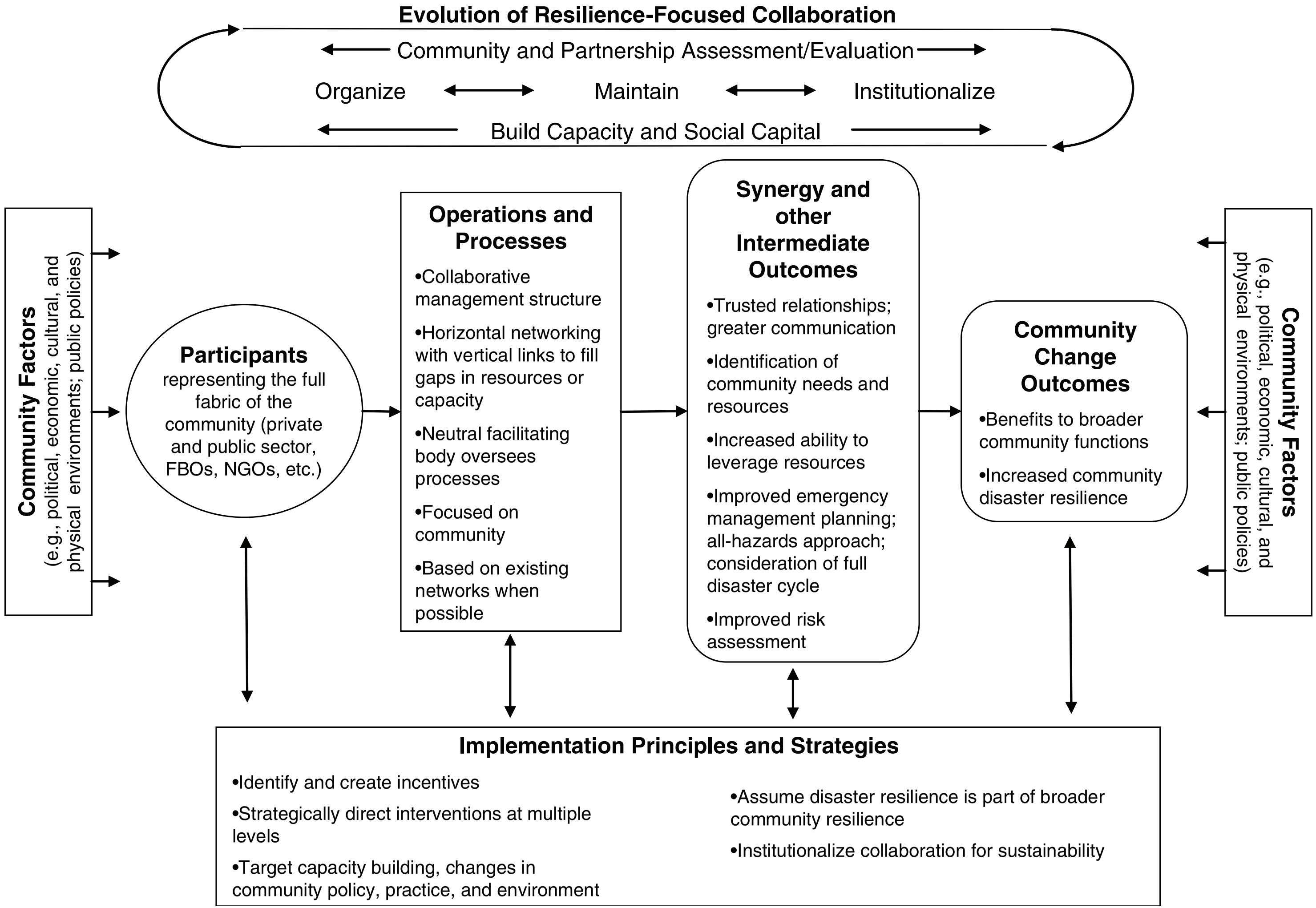

FIGURE 4.1 Conceptual model for private–public collaboration for building community resilience. SOURCE: NRC, 2011a.

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The next sections describe how the different components of Figure 4.1 are applied and modified for a framework for the dam and levee community.

Operations-Focused Engagement

Chapter 2 describes different community members and stakeholders to be engaged in resilience-focused efforts (Table 2.1): dam and levee owners, persons and properties at risk, the wider economy, and the broader social–ecological system. Response to a threat will be inadequate if collaboration does not include all elements of the community (NRC, 2010b). Just as community resilience depends on full representation, collaboration will be most successful if collaborators include those who have experience in the issues of concern but also diverse perspectives, experience, knowledge, and constituencies (Butterfoss, 2007). In developing a collaborative engagement approach, it is important to recognize and take advantage of existing formal and informal networks in a community, whether they are interpersonal at the neighborhood level or professional or social in and between private and public organizations. Potential participants in resilience-focused engagement can be chosen from among people who are well connected in those networks. Engagement for enhancing resilience with respect to dam and levee safety necessarily involves representation of stakeholders outside the immediate geographic area (e.g., those affected by indirect consequences of dam or levee failure) and state and federal regulatory entities that can have important supporting roles in resilience-enhancing processes.

Incentives to collaborate will differ among community members and stakeholders. Correctly identifying the elements of the dam or levee safety community as generalized in Table 2.1, assessing their various interests, identifying motivators for collaboration, effectively engaging them through efforts at various scales (e.g., one-on-one communication of resources or community-wide tabletop exercises), and effectively disseminating information to enhance risk awareness are dependent on an appropriate level of community member and stakeholder analysis and management of expectations.

Operations and Processes, Including Information Distribution

Participants in a prior NRC workshop on enhancing disaster resilience through private–public collaboration stressed the importance of some sort of collaborative management or facilitating structure that represents the community as a whole rather than a particular stakeholder interest or political leaning (NRC, 2010b). It is vital that the collaborative body be considered a neutral "honest broker" to gain the trust of the community. The activities of such a body will necessarily depend on the characteristics of the community that it will serve (NRC, 2011a), but an important role will be to remove the barriers that, for example, prevent the dam and levee safety community, emergency managers, and the private and public sectors

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more generally from operating independently of one another. As shown in Figure 4.1, operations and processes, including those established for information distribution, will be based on horizontal networking (within the community) and on vertical links to higher levels (state and federal) as necessary for resources that are not available in the community. The focus of activities will be based on collaboratively identified common goals and missions.

Strategies and processes are more likely to be effective if they are "based on resources and capacities available to the community" and efficient if they are "designed so that they are scalable and transferable to other collaborative and community efforts, regardless of the initial specific purpose" (NRC, 2011a, p. 52). For that to occur, the planning of strategies needs to be well informed with respect to what is achievable in a community. There is no reason to invent a new wheel for each new effort; efficiency is created when processes designed to work under particular circumstances can be modified as necessary to work under other circumstances. It should be understood that different community members and stakeholders will respond to efforts differently, and that different modes of engagement may be necessary for effective communication with different elements of society.

Engagement will likely be more successful if developed in a bottom-up manner at the community level; the mere initiation from the bottom is a foundation for building trust and acceptance of processes being established. To be clear: dam and levee safety professionals are not necessarily responsible for creating a new collaborative network in a community, but it is incumbent on them to seek ways to engage existing resilience-focused collaboration or to instigate the relationships that will be the impetus for such collaboration.

Outcomes of Collaboration

Two types of outcomes are shown in the conceptual model for collaboration in Figure 4.1: intermediate outcomes and community-change outcomes. It is easier to describe the difference between the two by describing the latter first. Community-change outcomes are changes in the community that increase the community's ability to prepare for, respond to, recover from, and adapt as a result of dam or levee failure. They include "changes in community policies, practice, and environment that result from enhanced community capacity and participation" (NRC, 2011a; p. 53). Intermediate outcomes are the benefits gained from the collaborative process itself. They are the enhanced relationships between and among organizations and individuals that result from

> increased communication and trust, identification of community needs and resources, increased ability to leverage community resources for the good of the community, improved ability to assess community risks, and improved emergency and community management and planning (NRC, 2011a, p. 53).

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Intermediate outcomes of collaboration can also include "an increased ability to resolve conflict within the community . . . and a shared sense of local community ownership and responsibility among community members" (NRC, 2011a, p. 53).

A Dam and Levee Safety-Specific Framework

Planning and constructing new and major infrastructure systems are more public today than in the past—public hearings are held, for example, to discuss design, permit approvals, community and environmental impacts, and financing. These public processes can have a major role in deciding the fate (e.g., to build or not to build) of major projects. However, maintaining and enhancing safety throughout the life cycle of civil infrastructure systems are, as the terms suggest, ongoing processes. Current safety practice typically does not extend to such issues as what constitutes acceptable risk in a community and how to maintain commitment to consideration of issues over the lifetime of a structure. Interaction needs to extend to post-construction and operational periods to support community resilience. Furthermore, public hearings and other activities tend to be conducted through "us and them" processes—infrastructure planners and designers provide information from one side of the dais, and members of the broader community react on the other side. Decisions are usually made elsewhere. Such interactions are not the equivalent of collaboration. Mechanisms for collaboration that expand beyond established safety practice are needed. Building and enhancing community resilience need to be continuous processes that are institutionalized as part of a community's normal functioning. Processes that allow engagement with representatives of all community members and stakeholders are needed.

Figure 4.2 is a conceptual framework for building community resilience with respect to dam and levee safety. It has many of the same components as the more general framework for resilience-focused collaboration shown in Figure 4.1 but is intended to communicate those components in a way specifically applicable to dam and levee safety programs. Central to the framework are collaborative processes for resource and floodplain management—the very reason for dam and levee infrastructure—that focus on aspects of dam and levee safety and community resilience. They include operational and risk communication, risk assessment, and preparedness and mitigation. An overarching element of the framework in Figure 4.2 is the availability to the community of dam and levee information that allows the community to stay informed about dam and levee infrastructure benefits and risks, operations, and procedures in place to respond to, recover from, and adapt in response to failure.

Dam and levee owners and operators provide services to a community and, in the case of dams, may also be lifeline resource providers. Both forms of infrastructure pose hazards. Collaboration serves as a forum for community members, stakeholders and dam and levee owners alike to address community resilience issues. The next sections provide a breakdown of each of the components in Figure 4.2.

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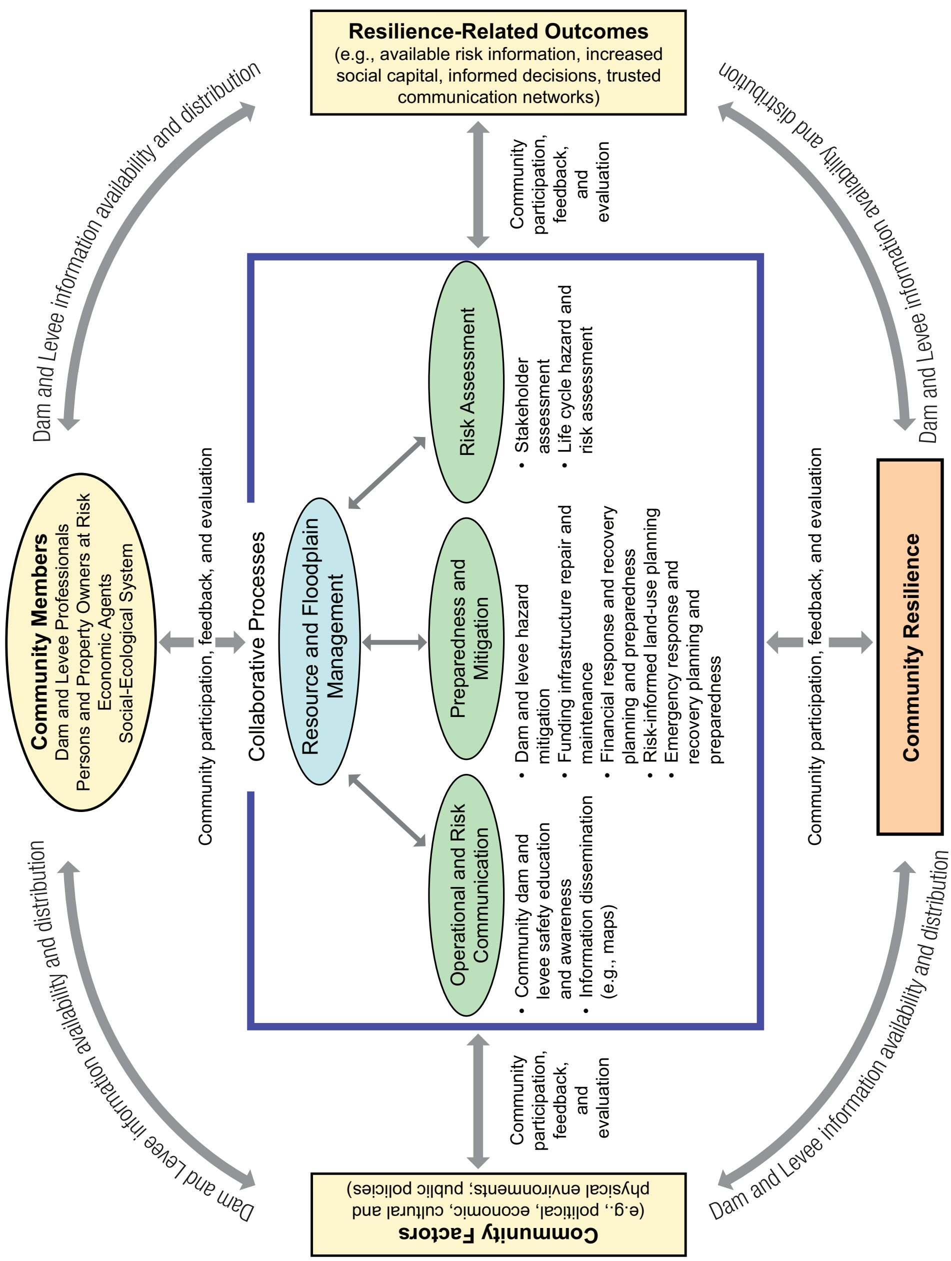

FIGURE 4.2 Conceptual framework for resilience-focused collaboration related to dam and levee safety.

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Community Members

Members of a community are defined in Chapter 2 and include dam and levee professionals, persons and property owners at direct risk, members of the wider economy, and the social–ecological system. In the context of this report, stakeholders—those may experience the indirect impacts of dam or levee failure, are included in the community.

Community Factors

There are numerous factors external to any collaborative effort that influence decision making and community resilience, including the political, economic, cultural, and physical environments. Policies that limit the ability to obtain inundation maps, for example, are external factors that affect communication, and therefore decision making. Some increases in exposure to flood hazards and increased occurrence of damage are rooted in government policies that support development in hazardous areas and in the desire of communities to increase population and the local tax base (Burby, 2006). Some policies that may contribute to increased exposure to flood hazards are established at the federal level (such as the National Flood Insurance Program)[4] and are exacerbated by lack of attention on the part of local governments to local risks and natural hazards (Burby, 2006). Building codes may not be enforced, and community leaders may not consider how flood-prone areas should be managed in comprehensive community planning. However, effective collaboration may ultimately influence some community factors as understanding and attitudes with respect to safety and resilience change community-wide. Dam and levee owners individually may not be able to influence national or even local policy directly. They can inform and influence decision making through collaborative social action.

Collaborative Processes for Resource and Floodplain Management

Dams and levees are designed to assist the use, development, production, protection, or management of resources, whether related to water, energy, land, or other types of resources. Collaborative processes can assist the management of resources by dam and levee professionals, community members, and stakeholders more broadly. The committee divides the many types of processes into three main categories: operational and risk communication, risk assessment, and preparedness and mitigation. Many specific issues will fall under multiple categories, and the list provided is not all-inclusive.

[4]See www.fema.gov/business/nfip/ (accessed January 29, 2012).

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Operational and Risk Communication

Fundamental to dam, levee, and community resilience are the availability of information and an understanding of individual and shared interests and needs. Processes that inform all community members and stakeholders of the benefits, risks, and operational features associated with dam and levee infrastructure are needed. These processes may involve public education and outreach (e.g., efforts similar to the California FloodSAFE program; see Box 3.7), education in operational risks associated with dams and levees (e.g., controlled flow of water that can lead to flooding and levee vulnerability during flood conditions), and developing a forum to raise and discuss issues associated with evolving community needs and expectations, dam and levee owner interests and issues (e.g., reservoir and recreation issues, coming dam safety modifications, and dam removal), and the community actions needed to answer or resolve the aforementioned. Making communities aware of who is at risk of inundation and other consequences of dam and levee failure informs risk reduction decisions and activities.

Risk Assessment

Through collaborative engagement, dam and levee owners and the broader community can assess hazards and risks associated with dam and levee infrastructure over the life cycles of dam and levee infrastructure and developed land. Infrastructure owners and the community can explore creative solutions for land-use problems to reduce the risk and consequences of flooding and to provide environmental and quality-of-life benefits for all. However, understanding who is at risk, and what kinds of preparedness, mitigation, and training efforts are best suited for different groups requires community member and stakeholder analyses. Such analyses also serve to inform collaborative efforts regarding the various types of economic, infrastructural, and human capacity resources available to address risk and resilience. Emerging owner, regulator, and broader community risks and issues, including the significant impacts of climate variability on dam and levee infrastructure, are also risks that will need to be considered.

Preparedness and Mitigation

Collaboration related to preparedness and mitigation can include activities such as dam and levee hazard mitigation, funding for infrastructure repair and maintenance, broader financial preparedness for response and recovery (e.g., ensuring that community members understand and are prepared for the financial fallout of dam or levee failure), and emergency response and recovery planning and preparedness. Community preparedness for the consequences of flooding, whether caused by operational circumstances, overtopping, or

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breach, includes, for example interacting with emergency management and other community leaders and planning and participating in tabletop and field exercises. Dam and levee failures are generally lower probability but higher consequence events (although the probability of levee failure is higher than typically associated with dam failure), and dam and levee safety professionals are uniquely informed in the community regarding the risks associated with dam and levee infrastructure, the sequence of events that occur before failure, and of flooding as a result of failure. It is their responsibility to take part in planning associated with transportation (e.g., as it is related to the provision of emergency services if roads or bridges are damaged or inaccessible), power generation and supply, water supply, public health issues, and so on. Establishing networks of trusted relationships and having processes in place before a failure occurs will make it more likely that response in the wake of a failure will be efficient and successful.

Risk-informed land-use planning can also be an aspect of hazard mitigation and certainly informs resource and floodplain management. Collaboration between dam and levee professionals and the broader community will allow more successful communication of information vital for land-use planning, and will provide an opportunity to influence policies and practices that can reduce exposure to flood disasters resulting from dam and levee failures.

Flood-risk management requires a long-term commitment of financial resources, particularly by dam and levee owners and operators, and potentially by any member of the community who is exposed to any type of flooding hazard. Dam and levee safety professionals understand the need for funding that is sufficient to cover maintenance, rehabilitation, upgrades, and eventual retirement of water management infrastructure. Depending on ownership and other factors, funds can come from fees, loans, taxes, grants, or intergovernmental transfers. The adequacy of the funding streams is particularly relevant to safety when maintenance and upgrades are deferred for lack of funds. One role for the dam and levee safety professional is to justify adequate funding, whatever its source.

To enhance community resilience, however, financial planning must go beyond consideration of infrastructure maintenance. As described in Chapter 2, the wider economy experiences flood impacts as a consequence of participation in the economy of an area, either as economic producers or as consumers. Because of these connections, the true "footprint" of dam and levee failure can extend far beyond the inundation zone and can sometimes be global. Resilience on the part of those economic agents includes the ability to handle the financial impacts of an economic dislocation. Community members and broader stakeholders may have different vulnerabilities, but in all cases it is necessary to be prepared for the financial consequences of a flood. Preparation may include the purchase of flood insurance, preemptive investments in flood-proofing, and relocation of vulnerable facilities. All such measures have costs, and so identifying funding sources is essential.

Through collaborative engagement, community members must be made fully aware of the physical risks and consequences of dam and levee failure. The complex webs of interactions

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among all agents need to be transparent so that all understand the potential for cascading consequences in case one part of the economic web suffers as a result of flooding. Dam and levee safety professionals, as participants in resilience-focused collaboration, can help all to understand what the direct physical consequences of failure could be in different scenarios and in turn can come to understand what the economic consequences might be for the broader community in addition to the dam and levee infrastructure. Dam and levee professionals who have that understanding may be able to make informed operational choices that reduce risk for the community while minimizing operational costs. Collaborative decision making can reduce community economic risk, reduce owner liability, and possibly reduce insurance costs.

Emergency response and recovery planning is a large component of community preparedness and resilience. Collaborative engagement that includes processes and mechanisms to prioritize preparation and mitigation activities should be informed by the participation of dam and levee professionals. Emergency management—and resilience building more generally—is necessarily a multidisciplinary, cross-jurisdictional, cross-sector endeavor. Without regular and trusted communications between those involved in emergency management, dam and levee safety experts, and other community members and stakeholders, emergency response and recovery will be less effective and efficient, and may lead to increased post-disaster hazards and a slower recovery.

Resilience-Related Outcomes and Resilience

Figure 4.2 refers to the benefits of resilience-focused engagement as "resilience-related outcomes." These can include increased access to risk information and social capital (e.g., more networking and increased trust among collaborators that can lead to more efficient communication and decision making). These intermediate outcomes are not equivalent to resilience, but are key factors in successful collaboration (thus, the two-way arrow between "resilience-related outcomes" and "collaborative processes").

In one sense, resilience can be thought of as the ultimate goal of resilience-focused engagement; however, a community is never "done" building resilience. Community members and stakeholders always change, community factors evolve, and infrastructure ages. Even meteorological conditions are variable and what might have offered satisfactory protection in the past may not be sufficient in the future. For this reason, levels of resilience can only be sustained and enhanced if collaborative engagement and action are responsive to changing hazards, risks, community capacities, and resources. Regular assessment and evaluation of community members and factors, desired outcomes, and collaborative processes is necessary to keep activities relevant. Institutionalizing resilience-focused collaborative engagement as part of dam and levee professional culture is the only means of ensuring that resilience-related efforts become part of the institutional memory, even when individual actors in collaboration retire or otherwise move on.

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CHAPTER FIVE

Tools for Building Resilience

As described in Chapters 3 and 4, there have been important improvements in dam safety in recent decades, largely because of improved regulatory oversight, increased owner compliance with dam safety requirements and attention to maintenance and inspections, and a better understanding of potential failure modes. Improvements in dam safety practice were accelerated by changes in legislation after a number of catastrophic dam failures in the 1970s. Since then, primarily in the wake of levee failures caused by Hurricane Katrina in 2005, a number of agencies have been making efforts to improve levee safety. Perhaps the most far-reaching has been the decision of the National Flood Insurance Program to deaccredit levees that could not be certified within 2 years as providing at least 100-year level of protection for structural or levee height reasons, and to require the purchase of flood insurance by property owners behind those deaccredited levees. Previously, those property owners had been exempt from mandatory purchase of flood insurance.

As discussed in Chapter 3, most safety improvement efforts focus on reducing the likelihood of failure. In the case of large dams, federal agencies and private dam owners routinely review dam safety, both through their own application of industry best practices and in compliance with state and federal dam safety requirements. But those steps address only one aspect of the risk equation: the likelihood of an adverse event, not its consequences. The potential consequences of dam or levee failure in many locations have increased and will continue to increase in part because of economic growth. Since the 1970s, many areas prone to inundation in the case of dam or levee failure have become developed with residential and commercial properties and associated critical infrastructure. In such circumstances, increased consequences of dam or levee failure can outweigh whatever reductions in risk may have resulted from improved regulatory compliance. Because the likelihood of failure can never be reduced to zero, *consequences* of failure must be addressed. Chapter 4 describes

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the committee vision for dealing with and learning from the consequences of failure through focused and active community collaboration to enhance resilience.[1]

Throughout the preceding chapters, the committee has described the types of tools, products, and guidance that could be developed at the federal level that would aid development of more comprehensive and effective dam and levee safety programs. The present chapter focuses on tools and methods that could support engagement of community members and stakeholders in collaborative efforts to improve community resilience, and provides information about community circumstances and priorities that can inform technical decision making. The assumption is that the primary proponents for selection and use of these tools will be dam and levee safety professionals. However, the broader community is an equal partner in the application of those tools and in enhancing community resilience. The chapter concludes with discussion of what the committee considers essential to successful incorporation of resilience-enhancing practices into dam and levee safety programs: evaluation of current safety program activities. The committee suggests a model that could be applied by safety programs and the broader community to assess processes that are in place and processes expected to be in place at given increments of program maturity.

Concepts of community resilience cannot be incorporated into dam and levee safety programs in one decision, action, or administrative fiat. Rather, improving resilience requires persistent and coordinated commitment and action—mostly voluntary—by many in the community. In all cases, methods and strategies for outreach and engagement are needed to create long-term and continuously improving relationships between owners, regulators, community members, and stakeholders more broadly. Successful integration of these concepts is supported by the identification and selection of the appropriate tools. But cases are community- and situation-specific, and so generic recommendation of the "best" tools is neither possible nor helpful.

Dam and levee professionals have direct access to much of the expertise and experience needed to develop, apply, or assess tools that can be used at the community level. Some of the expertise and tools can be found in the federal government. In some instances, it may be possible to modify or adapt an existing or developing tool to better meet community needs. In other cases, new tools are needed. The development of tools is best accomplished collaboratively across levels of government to take full advantage of the perspectives and knowledge of local and state entities and key stakeholders.

[1]Community is broadly defined in Chapter 2 to include dam and levee safety professionals, all other stakeholders, and the ecological and cultural values of the region.

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CHALLENGES TO BUILDING COMMUNITY RESILIENCE

A future in which communities are substantially more resilient to the effects of dam and levee failure is achievable, but only with much effort and change. The importance of recognizing the value of infrastructure services and the risks associated with them has been stated several times in this report. Dam and levee professionals must also recognize the benefits of collaborative engagement to enhance resilience. Community member and stakeholder needs must be met, including those associated with everyday services protected by dams and levees.

In working toward the vision described in this report, dam and levee safety professionals will need to change their professional culture. Some changes involve speeding up the current evolution toward risk-informed management. Others involve accepting an expanded role in safety management and related responsibilities, such as greater collaboration with the broader community. Public and private dam and levee safety programs provide a foundation for meeting those new responsibilities. At the same time, however, these programs face challenges, and even obstacles, that go beyond what can be required by law or regulation of a program. Similarly, challenges within communities as a whole make creating and participating in collaborative processes difficult, if not seemingly insurmountable. Recognizing challenges is an important step toward recognizing the opportunities that resilience-focused collaboration can offer. Tools to help overcome these challenges are discussed in this chapter.

Challenges for Dam and Levee Safety Professionals

Dam and levee professionals will need time to implement the changes suggested in this report. Challenges and obstacles beyond immediate control include the following:

- Public-sector dam and levee safety regulatory agencies have inadequate resources, making it difficult to keep up with current basic dam and levee safety duties. Consequently, additional and changed responsibilities will, at first, mean greater burdens in the face of limitations and cutbacks from state or federal legislative bodies. Legislators and other public officials who set policy will need to recognize themselves as part of the dam and levee safety community and understand—through collaborative engagement—the effects of their legislation on resilience.
- Public and private dam and levee professionals responsible for safety may be similarly overburdened. For example, according to the Association of State Dam Safety Officials (ASDSO), about 10 times as many dam inspectors as are now employed are needed to carry out regulatory mandates for inspections (ASDSO, 2011). Owners and corporate boards may limit the availability of corporate resources, including staff time.

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- Dam and levee safety professionals may be accustomed to an insular approach to safety and risk reduction, for example, identifying and remedying structural deficiencies and developing emergency action plans (EAPs). Their constituents often favor strengthening dam and levee infrastructure by using state or federal funds rather than local funding sources (Burby et al., 1991). Convincing their constituents that accustomed funding sources may not be available in the future, and that new approaches involving the broader community are required, is daunting.
- Government agencies and the private sector often are unable or unwilling to make vital public safety information available to communities. In the interest of national security, rules restrict access to some information that is necessary for a community to understand its exposure to risks associated with dam and levee infrastructure failure (see Box 5.1). Some conclude that the disadvantages of withholding data from the public are greater than the benefits of the presumed increase in infrastructure security, and that the practice of withholding information could be eliminated (e.g., Pitt, 2008). The inability to share information is a major barrier to communication, resilience planning, and success of the safety mission. This problem is made more difficult by the fact that dam and levee professionals, including those at the federal level, often lack skills in risk communication and collaborative engagement. Where there may be agreement that more risk communication is necessary, the effective means of conveying what risk is are not well understood. Further, current knowledge about risk communication does not permit conclusions about the best approaches to use under specific circumstances (Kasperson, 2005). Research in appropriate mechanisms and training in their use will be necessary.

Because community engagement is more efficiently developed from the bottom up, dam and levee owners, operators, and regulators will be more productive if they focus engagement efforts at the local level. Safety program professionals associated with locally owned and operated infrastructure may find it easier to interact with the local community because they already may consider themselves community members with multiple personal community linkages. Although they may not have the financial or other resources of larger infrastructure management entities, they may already have reasons beyond the professional for the continued safe functioning of infrastructure, and it may be easier for them to tap community networks and discuss the ties between infrastructure safety and community resilience. Their own professional and technical decisions may likely be more easily influenced by community member and stakeholder resilience needs and priorities. These professionals may be more easily convinced of the need for engagement, but may need assistance identifying and establishing ties with existing networks, or, in some cases, developing new networks. They may not have the skills or manpower for extensive outreach

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BOX 5.1
National Security Versus Safety and Resilience

One result of the September 11, 2001 terrorist attacks has been changes in policies and practices that restrict the availability of emergency action plans (EAPs) and dam failure inundation maps to affected communities and, in particular, to the general public (USACE, 2008; DOI, 2011). U.S. Army Corps of Engineers (USACE) interim guidance states that all copies of inundation maps shall be marked for official use only (USACE, 2008), indicating that the information can be disseminated only within the Department of Defense, "between officials of Army components and Army contractors, consultants, and grantees, as necessary, in the conduct of official business," and to officials of the "Executive and Judicial Branches in performance of a valid government function" (U.S. Department of the Army, 2000, p. 58). USACE provides the following guidance (USACE, 2008, p. 1):

> a. Part of the EAP. The primary use of inundation maps is to support the project Emergency Action Plan (EAP). As part of the EAP, copies of the maps may be given to the emergency management agency of communities or other jurisdictions that would be affected by a dam failure or other dam safety incident. The individual or office providing the map to the local jurisdiction should ask that the map be safeguarded and **not distributed to the public** [emphasis added]. We recognize that these agencies operate under various state laws concerning the release of information and may have to release copies under their laws and regulations.
>
> b. Public Meetings on Dam Safety. The inundation maps may be used in public meeting concerning dam safety. The maps may be displayed at the meeting and discussed. Copies of the full inundation maps for a dam shall not be distributed at the meeting without written approval from [Headquarters, USACE]. When a public meeting is advertised to cover a specific locality, the portion of the inundation map required for that locality may be extracted and used as handouts at the public meeting.

Such policies, however, can limit access to vital risk information and undermine efforts to meet public safety mandates, build resilient communities, and meet other community needs (e.g., Pitt, 2008). For example, in 2011, USACE wanted the Columbia County, Georgia Emergency Management Agency (GEMA) to remove emergency flood information from public access, according to a local news report (Beasley, 2011). Reportedly, the GEMA director responded, "it is my responsibility to talk to people about what hazards exist [and] what the risks are. . . . It makes sense, it's part of emergency planning to see what is the worst case that could happen and then let those people know so they know what to do" (Beasley, 2011). According to the news report, the 2005 map indicates that 7,000 people could be affected by worst-case scenario projections. Given the rapid growth in the county since 2005, the number is probably higher today. The GEMA director acknowledges that she does not expect a failure of the USACE dam, but is not willing to ignore the risk.

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and will need assistance determining how best to use the resources they have to make the necessary incremental changes.

Interactions become more complex, however, when infrastructure ownership and management are not local, or when the infrastructure includes miles of levees that run through multiple communities. In such cases, there may be a greater need to demonstrate the benefits of community engagement, and to plan the incremental steps necessary to engage the local communities, communities further afield (e.g., downstream), and with stakeholders more broadly. This type of encouragement could come from state and federal regulators and agencies.

Overcoming these and other obstacles is possible. Government and professional organizations (such as the Federal Emergency Management Agency, ASDSO, and the U.S. Society on Dams) can help the dam safety profession establish, refine, and expand its role through training, model programs, and the development of new tools. The notion of "levee safety," however, is relatively new. The lessons of Hurricane Katrina and other flooding and levee failure experiences have raised awareness of risks associated with levees. The levee community will need to continue to develop and define what constitutes a levee safety program and to develop standards of practice, training, model programs, and new tools for use by its professionals. Because dams and levees are generally part of a larger watershed system, many dam and levee operators—and the communities they serve—could benefit from collaboration in managing the overall drainage system and resources and reducing the likelihood and magnitude of individual and cascading failure events.

Community Challenges

Motivation for the community—particularly those vulnerable to flooding—to engage in resilience-focused collaboration is often not translated into substantive action. Elements of the public may not be aware that they live downstream of a dam and in the inundation shadow. Communities behind levees may believe the levees make them "safe" or protect them from flooding. Communities may be uninformed or misinformed because of a lack of information, or because the information they have is inaccurate or incomplete. Equally problematic is that community members may not fully comprehend the information provided.

Challenges to resilience-focused collaboration faced by the broader community may include

- an unwillingness to engage with dam and levee owners and operators,
- a lack of appreciation of the value of infrastructure (services provided, costs, and risks),
- active resistance to adoption of resilience measures by community special interests (e.g., real estate and tourism promotion),

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- a lack of reciprocal recognition of dam and levee owners' needs and responsibilities versus community goals and perceptions,
- an unwillingness of communities to consider hazardous areas in their comprehensive planning efforts (e.g., Burby, 2006),
- the need for state and local governments (and lack of resources) to carry the financial burden of development constructed in harm's way (Burby, 2006).

CHOOSING TOOLS TO ENHANCE COMMUNITY RESILIENCE

A variety of methods, techniques, measures, and approaches are applicable to efforts to improve community resilience to dam and levee failure. They may be structural or behavioral, mandated or voluntary, and individual or community-wide. They are all intended to improve the ability of a community to avoid and recover from an adverse event, that is, to reduce the magnitude and duration of severe consequences of an event. The committee characterizes all these methods, techniques, measures, and approaches as tools for improving resilience. Their success depends on the availability of adequate relevant information about risks and on agreement on a course of action that meets the needs of dam and levee professionals, community members, other stakeholder groups, and local and state governments.

The Federal Interagency Floodplain Management Task Force (FIFM-TF, 1994) stated that managing flood hazards "encompasses both the process of making decisions and the continuous challenge of seeking out and developing new strategies and tools to encourage the wise use of floodplain lands" (p. 9). It noted that "using one or more . . . strategies (and the tools that implement them) helps bring existing or proposed activities into compatibility with the risks to human resources and the risks to natural resources" (p. 9). These strategies include the following (p. 9):

- "Modify human susceptibility to flood damage and disruption.
- "Modify the impact of flooding on individuals and the community.
- "Modify flooding.
- "Preserve and restore the natural resources and functions of floodplains."

The committee adapts these strategies, which focus on the concept of safety, and expands them to incorporate concepts that support resilience:

- Develop approaches to identify community members and stakeholders, engage in resilience-focused collaboration, and communicate risk in clear, understandable, and actionable terms.
- Determine characteristics of resilience for the community and decide on objectives to make the community more resilient.

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- Adopt an overall set of resilience systems-engineering principles and practices to deal with the uncertainties and complexity inherent in dam and levee safety.
- Reduce the likelihood of harmful events.
- Reduce the consequences of dam or levee failure for the community.

Each of the strategies relies on a set of tools that in combination can enhance dam and levee safety and resilience.

An assessment of existing community resilience programs and their strategies allows the community to set realistic objectives and to identify additional tools that are likely to provide cost-effective reductions in risk and improvements in overall resilience. Some communities may already apply an all-hazards approach to improving community resilience. In such cases, it is desirable for a dam or levee safety program to align itself with existing efforts rather than create a new and possibly conflicting community effort; tools already in use may be sufficient or may need some modification to accommodate dam and levee safety-specific issues.

A means of assessing progress in risk reduction and improving resilience is described later in this chapter.

Reducing the Likelihood of Harmful Events

The likelihood and location of flooding depend on hydrologic and upstream and downstream conditions, dam and levee design and operation, and failure mode. At a minimum, the design and operation of dams and levees would include using tools that quantify and reduce the likelihood of failure. Chapter 3 discusses the progression of safety practices from standards-based methods to more risk-informed approaches. Still better for the broader purpose of reducing risk are methods for designing and operating dams and levees that address the direct and indirect consequences of failure and thus provide some basis for departing from traditional criteria when indicated.

Another way to reduce or modify the likelihood of flooding and its consequences is to promote individual and collective action through financial incentives. For example, changes in reservoir allocation procedures can allow downstream interests to purchase increments of reservoir capacity for flood storage, diverting it from other uses. The reservoir could then be operated in such a way that the purchased increments of capacity are normally empty; this increases the effective flood storage of the reservoir and reduces the likelihood of dam failure during flood events. However, such a strategy could have the unintended consequences of amplifying the vulnerabilities of some communities that lack resources. Collaborative consideration of community and stakeholder needs and priorities is especially important to avoid hidden consequences. Additionally, whether that strategy is cost-effective depends on the cost of compensating displaced storage uses compared with community benefits from

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the increase in safety and reduction in risk. Once legal and regulatory authority allows such transactions, a role of dam safety professionals is to assist the community in evaluating all aspects of the issues.

Another commonly used method on large rivers, such as the Mississippi, is the purchase of flood easements, which make it possible to divert flood flows away from the river channel and ease pressure on downstream levees and communities. Financial incentives to landowners may be coupled with appropriate changes in the governance framework to define the circumstances under which diversions could occur.

Reducing the Consequences of Dam and Levee Failure

Identification and selection of tools that assist communities in withstanding the effects of dam and levee failure occur during the preparation and revision of hazard mitigation plans, which can stand alone or be integrated into a comprehensive urban development plan. Citizen involvement in mitigation planning is vital if tool selection is to reflect community interests and values. For example, citizen involvement in flood risk assessment and mitigation planning is required in the member states of the European Union (see Box 5.2).

BOX 5.2
European Union Requires Public Participation in Flood Risk Assessment and Management

The European Union, through its directive on the assessment and management of flood risks (Directive 2007/60/EC), requires member states to carry out preliminary assessments of flood risks to flood-prone river basins and coastal areas. For zones at risk, the directive requires member states to draw flood risk maps and prepare flood risk management plans. It also states that the public will be involved in production, review, and updating of all assessments, maps, and prepared plans. All such products will be publicly accessible so that citizens and other interested parties can have a say in the planning process.

SOURCE: EU (2007).

Various tools have been identified by planners and others to improve a community's ability to be resilient in the face of dam or levee failure, including

- requirements to provide flood hazard information through delineated flood hazard zones on subdivision plats, through disclosure of hazards by real estate agents, and posting of signs warning of hazards (e.g., high-water marks on historical markers);
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- zoning ordinances for land use and land development (e.g., for regulating housing developments);
- land acquisition (e.g., purchase of riparian land for open space, vertical parks, or greenways, land easements, or development rights) to move levees back from the river, or for removing previous development from flood hazard areas (see Box 5.3 for an example from the Netherlands); and
- tax adjustments, for example, reducing property taxes for low-intensity land uses in floodplains, or limiting property tax increases on property improvements that reduce the effects of flooding.

A different kind of financial incentive could require each property owner to pay an amount equal to the amortized cost of flood hazard reduction infrastructure (e.g., dams and levees). For example, a community could itself construct levees, financing 100 percent of the project with tax revenue (full-cost pricing). The community as a whole would then be motivated to find a combination of hazard reduction infrastructure and resilience-improving measures to minimize total cost. Such tradeoffs are rarely considered; local communities do not typically pay the full cost of dams or levees. For that reason, resilience improvement seems expensive in comparison, because the alternative (hazard reduction) appears to be inexpensive or free. A rational community, responding to these incentives, might demand higher dams and

BOX 5.3
Room for the River Programme in the Netherlands

The combination of extremely high water levels in the Rhine and Meuse Rivers in 1993 and 1995—barely contained by existing dikes and the cause of evacuation of one-fourth of a million people—and expected increases in water discharge in rivers as a result of climate change prompted the Dutch government in 2007 to implement a different approach to flood risk management and safety. The old approach, dominated by increased heights and sizes of dikes, was replaced by an approach that makes more room for the river, improves safety, protects the land and people living behind the dikes. The Room for the River Programme, expected to be completed by 2015, will provide flood control by allowing the branches of the Rhine to expand naturally during higher levels of water dischage at over 30 locations. A variety of measures are being implemented, such as lowering the floodplains, deepening the summer beds, and moving dikes further inland. The program stipulates that only when alternatives to create room for nature are infeasible will measures to strengthen dikes be implemented. The program is expected to improve safety but also to improve environmental quality of the river region, and provide opportunities for public–private partnerships.

SOURCE: Room for the River Programme. Available at www.ruimtevoorderivier.nl/meta-navigatie/english/ (accessed January 21, 2011).

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levees while neglecting any effort to increase resilience. An example of full-cost pricing for flood-hazard reduction is the Miami (Ohio) Conservancy District, which has long provided flood management services while collecting the full cost of doing so in the form of special benefit taxes from the properties that benefit from management activities (see Box 2.1).

Strategies that reduce the likelihood of dam or levee failure and susceptibility to related consequences, no matter how well devised and implemented, can be overwhelmed by large storms or unforeseen events (such as errors in dam and levee design or operation and maintenance). When a dam or levee failure occurs, its effects on members of the community and stakeholders more broadly can be ameliorated or redistributed in time and space with appropriate tools such as those that assist

- emergency preparedness, including for emergency preparedness planning, regional public health planning, flood warning, flood fighting, evacuation, and sheltering;
- identifying and obtaining disaster relief from government and nongovernment sources;
- individuals and businesses to secure flood insurance to protect property and belongings;
- effective predisaster planning for post-disaster recovery and reconstruction, including the identification of staging areas and sites for temporary housing;
- relocation of structures out of the inundation zone.

Some tools assist the community to become more resilient by providing specific information, for example, on the number of people likely to be injured or killed as a result of a given event, and the time required for evacuation. One such model is the Life Safety Model used by the Canadian power-generating company BC Hydro.[2] Equipped with such information, a community can design better evacuation plans and other strategies to reduce exposure of threatened populations.

Environmental resilience is a part of community resilience, and floodplains provide important habitat for plants and animals, and migration corridors for many species. Protection of floodplains from development can result in wildlife protection, lowered potential flood heights, protection of downstream development from flood damage, improvements in water quality, and preservation of environmental amenities for educational and recreational purposes.

Strategies commonly employed to preserve and restore natural resources and functions of floodplains include

- Public acquisition of floodplains (see Box 5.4);
- Acquisition of floodplains by land trusts and other nonprofit organizations (see Box 5.5);

[2]See www.lifesafetymodel.net (accessed January 21, 2011).

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- Regulations that sharply limit the intensity of development in floodplains, including wetlands ordinances, overlay zones, and cluster and transfer of development ordinances;
- Tax incentives that grant lower property taxes to owners who agree to keep their land out of development, especially by dedicating open-space easements to the public.

Engaging the Community

Individuals, organizations, and local governments can improve community resilience through structural modifications (e.g., flood-proofing, structure elevation), land-use decisions (e.g., building outside flood-prone areas, and locating utilities and critical infrastructure where the direct and indirect consequences of dam and levee failure will

BOX 5.4
Dike Relocation in the Elbe River in Germany

To cope with flood disasters, the northwest federal state of Brandenburg, Germany, implemented multiple flood prevention measures along the Elbe and Oder Rivers, including strengthening, raising, or setting back existing dikes (Drees and Sünderhauf, 2006). A first project was the relocation of the Elbe dike at Lenzen, which was triggered by the need for structural rehabilitation. About 420 hectares of ecologically important floodplain were restored to the area by moving the dike farther from the river (see figure). The project was initiated in 2002 and completed in 2008 and resulted in a lowering of water levels, reduced stress on the dike, and reduced threat of dike failure (Grajales-Mesa et al., 2010).

Simultaneous with the technical efforts were efforts to consolidate land into public ownership, strengthen agricultural production, and stimulate ecologic preservation, tourism, and village renewal (Drees and Sünderhauf, 2006). Key barriers to such ambitious projects have included inflexibility of existing policies and lack of interpretation of national policy at the local level, funding, institutional and administrative boundaries, lack of scientific demonstration of benefits, the need for community and stakeholder involvement, and especially the need to purchase land or change land use (RESTORE, 2011). Innovative methods were needed to resolve conflicts between agricultural, environmental, tourism, fisheries, transportation, energy supply, municipality, and flood prevention interests. Private owners who refused to sell their land were allocated property behind the new dike after intense negotiations (Drees and Sünderhauf, 2006). Obstacles were overcome by identifying appropriate funding structures and varied sources of funding, designating a network management group to manage the project, and effective stakeholder engagement (RESTORE, 2011).

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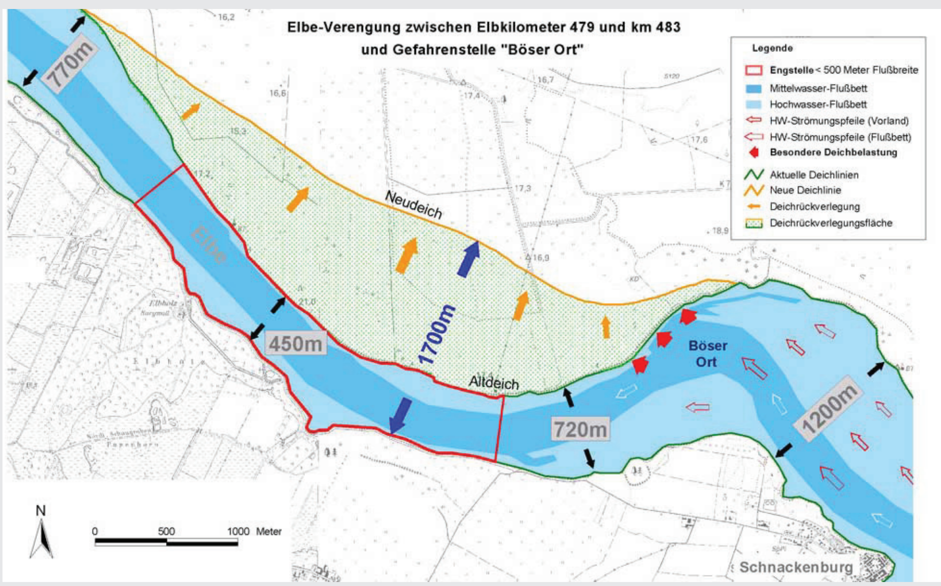
be less severe). As members of the larger community, dam and levee safety professionals with federal agency support, can demonstrate for each situation the specific benefits of the processes that improve community resilience, and can themselves realize the benefits of the improved resilience. Dam and levee professionals have traditionally disseminated information related to infrastructure operation and emergency action planning, but may need guidance from the federal government and professional associations regarding how to identify and engage community members and stakeholders for enhanced information sharing, collaborative land-use planning, financial planning, EAP preparation, and resource and floodplain management. Accurate and credible information on the nature of dam and levee risks needs to be shared. Tools that provide information on the vulnerability of critical infrastructure—such as utilities, transportation arteries, and public facilities essential to the continuing community function—will allow communities to take effective actions to improve resilience.



Relocation of the Elbe River dike in Lenzen that restored 420 hectares of ecologically important floodplain, lowered local water levels (without lowering downstream water levels), and reduced stress on the dike and the risk of flooding. SOURCE: Grajales-Mesa et al. (2010).

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BOX 5.5
Reconnection of Floodplain and River in Belgium

The European Union (EU) LIFE[a] Project (LIFE98/NAT/B/005171), which reconnected the Dijle River and floodplain in the valley south of Leuven, Belgium, resolved two competing interests: nature conservation and flood prevention. The Dijle valley is home to wetlands, ponds, and swamp forests, which are valuable for floodwater retention in the region; however, agricultural development had diminished the valley's natural capacity to retain floodwaters and resulted in increased flooding in parts of Leuven. A plan to construct a flood retention reservoir was proposed, but was dismissed after meeting resistance from local conservationists. The final solution—reconnecting the river and floodplain—allowed restoration of the valley's natural flood retention capacity while preserving its alluvial habitats and protecting the interests of the local populace. The LIFE project overcame several potential barriers—conflicts over land ownership, local resistance from farmers, and overall cost—by setting priorities for land purchase through a conservation nongovernmental organization, providing compensation to affected farmers, and avoiding the more expensive solution of a large retention reservoir. The project achieved two main results: it contributed to more natural and less destructive flooding dynamics in the Dijle valley, and it secured large blocks of overgrown land and restored them with natural grassland habitats, partly through a direct marketing scheme with local farmers.

[a]LIFE is the EU's financial instrument for supporting environmental and nature conservation projects throughout the EU.

SOURCES: RESTORE (2011); see also EU LIFE Project (LIFE98/NAT/B/005171), available at ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=299.

Expanding risk-communication programs to include two-way risk communication early in decision-making processes will help minimize conflicts based on differences in expectations, and will help build social capital and promote the ability to act on increased knowledge (Kasperson, 2005). Public outreach and risk communication programs can expand current efforts associated with, for example, public hearings, citizen advisory committees and task forces, alternative dispute resolution, citizens panels, surveys, focus groups, technology-based approaches, and development of different deliberative methods (e.g., see NRC, 1996, for explanation of these various activities). Such efforts are important in informing resilience-focused collaboration, as are other community-based activities such as involving those at risk in surveillance demonstrations with professionals, and incorporating community risk and preparedness concepts in primary and secondary school curricula. As already described, discussion and feedback are vital for collaborative engagement, and dam and levee professionals and the communities they serve need assistance identifying mechanisms for engagement, whether for enhancing dam and levee safety related to infrastructure operations or for providing their expertise in land-use, floodplain, or financial management.

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ASSESSING THE STATE OF PRACTICE WITH RESPECT TO RESILIENCE

To improve safety programs and community resilience, it is essential that current program practices be evaluated and decisions be made about which tools—implemented to what degree or with what coverage, and at what level—are most appropriate and beneficial given the abilities of a program at a specific time. This requires the ability to assess the present state of practice with respect to resilience and to identify where additional efforts are needed. To assess the state of practice, the committee introduces two concepts:

- *Tool maturity.* A tool can be applied in different ways, for different reasons, or with different degrees of coverage of a community. A tool is said to be more mature if it improves how well a process is accomplished and if its use increases or leads to an increase in resilience.
- *Maturity matrix.* A maturity matrix is a table that displays the relative maturity of efforts, for example, efforts to improve resilience. Rows of the matrix correspond to specific program activities and goals. Columns, moving from left to right, reflect continuous improvement in tools or processes and indicate level of maturity. The cells of the matrix contain specific tools and processes; their position depends on the related program goal and relative maturity of a tool or process. In addition to characterizing the current state of practice, the maturity matrix provides a systematic approach for identifying opportunities and priorities to improve processes and increase resilience.

The remainder of this chapter is devoted to the concept of maturity and its assessment. The chapter concludes with an example of a tool that can be used by dam and levee safety programs to promote program and community-level engagement, assess processes that are in place, and establish and set priorities among goals.

Maturing a Tool

The effectiveness of a tool or process in improving community resilience depends in large part on using the tool of the right maturity level for the given circumstances. This principle can be illustrated by considering an important tool in use by dam owners: periodic safety reviews for identifying potential and actual structural deficiencies. The U.S. Army Corps of Engineers has conducted safety reviews of dams since the 1970s, and since enactment of the National Dam Safety Program Act in 1996,[3] has inventoried dams and identified those that pose hazards to downstream populations and property. Safety reviews

[3]The National Dam Safety Program Act was passed as part of the Water Resources Development Act of 1996. See epw.senate.gov/dam.pdf (accessed February 9, 2012).

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originally were intended to provide a sense of where a dam stood relative to a limited set of deterministic engineering standards, such as the ability of a spillway to discharge the inflow design flood, and the stability of structures against overturning and sliding failures under a variety of loading conditions. Although rudimentary, the measures were straightforward to calculate and provided some consistency in screening criteria.

One result of early dam safety reviews was that dam owners were forced to undertake expensive rehabilitation to meet the standards-based criteria. Despite those efforts, dams continued to fail. For example, the Taum Sauk Pumped Storage Project reservoir—built in 1965 in the Missouri Ozarks—met Federal Energy Regulatory Commission (FERC) standards in a number of safety reviews, but the reservoir failed catastrophically on December 14, 2005. Post-incident investigations pointed to a number of causal factors that allowed the reservoir to be overfilled and fail, including the miscalibration of a water level gauge and a lack of redundancy in instrumentation that would have caught the error (FERC IPOC, 2006). The state of practice of dam safety reviews at the time could not account for such factors.

To address inadequacies observed in FERC's dam safety review process, FERC introduced the Potential Failure Mode Analysis (PFMA) process, which owners are now required to apply. PFMA is intended to capture the "chain of events leading to unsatisfactory performance" (FERC, 2005, p. 14-2) that might not be detected through standard reviews (FERC, 2005). Failure mode analysis had been practiced by a number of progressive dam owners, but was not a standard practice in the industry. PFMA improves an owner's ability to understand how a dam system performs, to identify events and conditions that could lead to unsatisfactory performance (including dam failure), and to put appropriate controls into place. This process allows dam safety reviews to mature beyond assessing whether a dam meets design standards. PFMA allows operational measures that affect performance and safety to be addressed—a true maturation of the review process.

PFMA represented an early stage of risk assessment, but there remained a need to move beyond the qualitative and into quantitative risk analysis. Quantitative risk analyses were relatively new to dam safety professionals, but applications in other fields, such as nuclear energy, offshore oil and gas production, and other hazardous industries, could be drawn on (Ibrahim et al., 2001; SEI, 2010a; NASA, 2012). Eventually, procedures were developed for risk-informed safety reviews and calibrated against procedures used in other hazardous industries to clarify the divisions between risk criteria (unacceptable risk, tolerable risk, and acceptable risk). This is the state of advanced practice applied by some in the dam safety industry, although it is not universally applied. The maturation of the safety review process continues, led by a number of professional organizations and risk practitioners in the dam safety field.

Some members of the dam and levee safety community do realize the benefits of a safety program that includes elements of community resilience. However, even the relatively

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mature practice of safety review falls short of fully integrating concepts of community risk reduction and resilience because communities likely have not been engaged in negotiating the criteria for defining risks or in choosing and implementing appropriate tools to minimize or deal with risks. The next steps in the maturation process include evaluating practices against actual community priorities to define what constitutes acceptable hazard reduction and community resilience.

Figure 5.1 shows the evolution of dam safety analysis as a maturing tool, ranging from its earliest, most simplistic forms to a fully matured risk-based assessment process that incorporates community values. In this case, the current state of dam safety analysis for most dam owners is near the middle of the scale, where failure mode analysis is practiced by many large dam owners and some analyses include quantitative risk assessment. However, even when quantitative risk assessment is applied, the decision criteria are typically those of dam owners rather than of the broader community. Resilience will be improved when dam safety reviews mature and include the community in defining decision-making criteria.

History of Assessing Process Maturity

Dams and levees serve a wide variety of functions and provide an array of services to a broad community of commercial, institutional, and civic stakeholders. Dam and levee professionals manage a complex "package" of procedures and deal with a large and diverse community of stakeholders. The status and maturity of complex processes are systematically assessed in a number of fields, sometimes under the rubric of "resilient systems engineering" (Jackson, 2009). In some cases, such assessments use a maturity matrix to display maturity status and highlight opportunities for improvement and prioritization of processes.

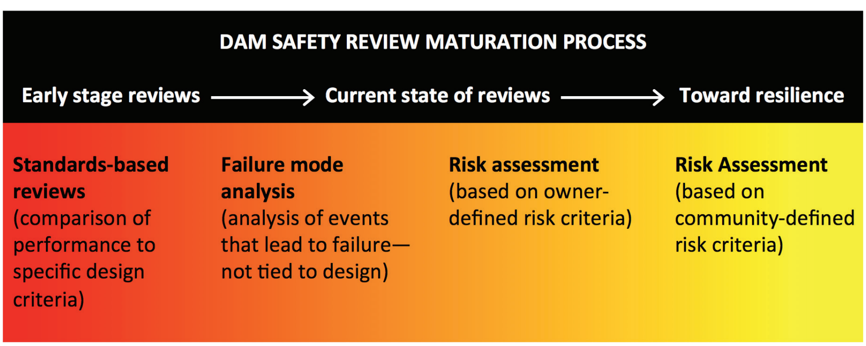

FIGURE 5.1 The dam safety review maturation process. The continuum of the process begins with deterministic processes, such as are mandated by the National Dam Safety Program Act in 1996, and continues through advanced processes of risk-based assessment conducted with full input from the community.

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The Capability Maturity Model Integration (CMMI) concept was originally proposed for the software and systems engineering industry to address the daunting complexity of developing software products and processes and the effects of their failure (Paulk et al., 1994). This application later expanded to encompass all systems (SEI, 2010b). Over the last decade, the model has been extended to personnel, supply management, and manufacturing. The model is also used in the electricity generation industry (e.g., Hydro Quebec, 2010). The CMMI concept was further adapted to characterize the preparatory measures needed to improve the capacity of communities to withstand a catastrophe (King, 2010). Ontario Power Generation (OPG), operating 240 dams and 65 hydropower stations in the Province of Ontario, Canada, has developed a model similar to that of the CMMI concept and applied it at a detailed level to assess its ability to manage flood events and their effects on dams (Bennett and Sykes, 2010).

CMMI was developed to gauge improvements in product and service development, but it is not limited to this application. It incorporates best practices with respect to development and maintenance activities for the duration of the product or service life cycle. CMMI is a framework to describe the key elements of an effective process, including operations and maintenance, and stakeholder involvement. CMMI guides the evolutionary improvement that occurs incrementally from ad hoc immature activities to mature, disciplined processes. The processes are improved by the introduction of more advanced (mature) practices specific to the particular product or service being developed.

When applied to processes required for product and service delivery, CMMI generally defines maturity according to five levels: (1) merely performing the activity, (2) planning and executing the process in accordance with policy, (3) tailoring the process using the organization's set of standard processes and guidelines, (4) management that includes quantifying product and service quality, and (5) changing and adapting successively to meet current projected business objectives (SEI, 2010b).

Engaging stakeholders about specific engineering, management, and support operations has proved successful in delivering value (related to schedule, cost, and quality) to organizations that have adopted CMMI (Goldenson and Gibson, 2003). The CMMI approach defines a stakeholder as a group or individual affected by outcomes of a process, and the CMMI process requires integrating stakeholders into process development. Stakeholders include residents and customers as well as managers, operators, and regulators accountable for outcomes. Relevant stakeholders are identified to participate in specified activities. Without such involvement, process improvements are less likely to occur or will occur more slowly. Stakeholders are brought into the process as it matures from a basic to a managed process (e.g., from the third to the fourth level as described above). This is challenging in part because of the broad interests of stakeholders, and because they have been traditionally outside decision-making processes.

The application of CMMI or related methods to dam and levee systems may result in

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opportunities to change the dam and levee safety cultures in ways that will contribute to enhanced safety and resilience. Transition from structure-centric solutions to stakeholder-centric and outcome-driven solutions is necessary for dam and levee safety programs to mature. Using an approach similar to CMMI allows dam and levee professionals to address infrastructure safety as a system rather than as a collection of loosely connected components. A description of how such an approach could be used by dam and levee professionals to build community resilience into safety programs follows.

Assessment of Community and Stakeholder Engagement

The committee presents a tool to facilitate a common understanding among all community members and stakeholders of the shared and individual responsibilities, risks, and processes associated with continued safe operation of dam and levee infrastructure and the continuum of measures to improve community resilience. Tools that ensure transparency and understandability at the community level, both in and outside dam and levee safety programs, are fundamental to success; the Maturity Matrix for Assessing Community Engagement, described below, is such a tool. It is based on the CMMI concept and, like CMMI, it uses a maturity matrix to illustrate and summarize system status. The maturity matrix introduced here considers five levels of maturity for each set of processes or goals, which are gauged with respect to relative success in enhancing community resilience. Table 5.1 defines levels of maturity with respect to regulatory compliance, best industry safety practices, and contributions to resilience. The maturity levels should not be seen as discrete conditions; rather, they exist on a continuum of practices, from those that do not contribute to community resilience (Level I) to those that do the most to enhance resilience (Level V).

On the basis of the descriptions in Table 5.1, the committee derived, for illustrative purposes, a generic and rough outline of a maturity matrix with a few examples of specific tools applicable at different maturity levels. Table 5.2 provides a general idea of how a maturity matrix could be constructed for a community. Because of the unique risks, resources, and priorities of a given community, actual maturity matrices developed for a specific community will have many more rows and detailed descriptions of specific tools. OPG, for example, has generated a highly detailed maturity matrix for its operations intended to move its program toward industry best practices.[4] In the consideration of flood management alone, OPG identified 14 areas of activities, each of which was subdivided. If the matrix maturity had been extended to processes involving community collaboration and consideration of community member and stakeholder priorities, the matrix could have been larger. In developing its matrix, OPG defined the scope of the program and identified the purpose, goals, and objectives to develop or improve the program.

[4]T. Bennett, OPG, presentation to committee, May 5, 2011.

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TABLE 5.1 Description of Maturity Levels

Level I	Level II	Level III	Level IV	Level V
Poor performance	Currently accepted practice or regulatory compliance	Current best practice (due diligence)	Best practice plus community/ stakeholder input	Best practice plus full community/ stakeholder collaboration
Ad hoc practices; inconsistent with industry practice or with regulatory compliance	Meeting minimum levels of industry practice or regulatory requirements	Level II plus additional measures based on industry best practice or due-diligence analysis	Level III plus additional measures reflecting dam and levee safety professionals' objectives and priorities but with consideration of community input	Level III plus additional measures based on robust community and stakeholder input, including collaboration on both tools and goals; decisions reflect community objectives and priorities

Operationalizing community resilience requires a toolset of various analytical models (e.g., the assessment of interdependencies, of regional economic, environmental, and societal impacts, or regional risk assessments), best practices, and guidelines for community and multijurisdictional community resilience. Because it is not currently possible to measure resilience directly, assessment of actions taken to enhance resilience is necessary. The first steps in applying the Maturity Matrix for Assessing Community Engagement are to define what is to be evaluated (e.g., safety program areas or community practices) and then to define in the maturity matrix the existing conditions and tools already in use. The level of detail of the matrix will need to be decided upon and will depend on expertise and other resources available for the job. Depending on the level of detail desired, there may be many rows outlining specific goals and activities.

Development of the existing-condition maturity matrix is useful for a number of reasons. For example, compiling the matrix facilitates a complete assessment of a safety program and all its safety, communication, and engagement processes. It compels dam and levee owners to scrutinize current technical and resilience goals and processes, and it helps them set and prioritize goals for increased safety, engagement, and resilience. The more detailed the matrix, the more rigorous the scrutiny will be. Additionally, the matrix itself becomes

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a tool for communication among dam and levee professionals and the broader community. The committee found even the development of the matrix concept useful in bridging communication gaps among those with different expertise. In collaboratively evaluating and deciding on processes to populate the matrix, dam and levee professionals and the broader community can learn a common vocabulary.

Once the existing-condition matrix has been developed, it becomes a transparent mechanism for planning and evaluating processes intended to enhance technical decision making and community resilience. Opportunities for improvement become immediately apparent. Processes that are less mature can be visibly highlighted, and priorities for improvement can be chosen, for example, on the basis of availability of funding. Regular assessment of safety and resilience programs using the matrix can result in visual updates that reflect changing conditions.

The matrix can assist decision makers in seeing which tools need to be added or augmented to bring the safety program and community up to target levels of safety and resilience. The maturity matrix and the procedures for designing and using it constitute assessment of community and stakeholder engagement. Once introduced to the community, this tool can be a powerful communication aid that allows all to understand why some tools or processes are more desirable than others and how priorities are defined. Safety programs and communities can create extremely detailed maturity matrices that can serve to inform all manner of technical decisions, or decisions related to social aspects of enhancing resilience. The Maturity Matrix for Assessing Community Engagement supports communication and engagement by providing visual pictures of existing conditions and of planned improvements while incorporating the technical detail needed for implementation and assessment.

The Federal Role in Assessing Community and Stakeholder Engagement

Creating a maturity matrix for assessing community engagement is a complex process that will be, to a great extent, unique to each community, just as the maturity matrix itself will be. Dam and levee safety programs and communities will need assistance in understanding the maturity matrix and its application and will need incentives to make the effort. The application needs to be at the community level to be effective. The committee provided a generic outline of such a tool, but the federal government could conduct research and further develop a framework for its application, and training for its use. It may also be beneficial to facilitate a pilot application in a community to research and demonstrate its utility.

With better understanding of the maturity of safety programs and community resilience, the agencies that support dam and levee safety programs could have the information needed to enhance communication with programs and communities to, for example, build knowledge and solicit community and stakeholder concerns. They may be able to assess when to loan staff to assist with the preparation of community hazard mitigation plans and

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TABLE 5.2 Sample Entries for a Maturity Matrix for Assessing Community Engagement

Elements	Level I	Level II	Level III
Dam or levee safety reviews	No activity	Standards-based only	Introduction of additional review criteria (e.g., failure mode analysis)
Other programs related to conventional dam/levee safety activities	*Each tool is defined at different levels to show progression from minimum activity (Level I) through best industry practice to full community member and stakeholder engagement and collaboration (Level V)*		
Emergency action plans	No activity	EAPs developed internally by owner	EAPs developed with input from emergency management agency
Specific tools related to emergency planning response, including development of community preparedness measures, warning and evacuation procedures, and recovery plans	*Each tool is defined at different levels showing progression from minimum activity (Level I) through best industry practice to community member and full stakeholder engagement and collaboration (Level V)*		
Floodplain management	No floodplain management plans	Floodplain management plans in place	Floodplain management plans accommodate shadow floodplain associated with catastrophic dam or levee failure
Specific tools such as those related to land-use planning and floodplain management, including initiatives for financial incentives and zoning reform	*Each tool is defined at different levels showing progression from minimum activity (Level I) through best industry practice to community member and full stakeholder engagement and collaboration (Level V)*		

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Level IV	Level V	Examples of Possible Outcomes
Application of quantitative risk assessment by using criteria developed by owner or regulator with input from community members and stakeholders	Application of quantitative risk assessment by using criteria that reflect the community's societal values	Community is fully apprised of current level of risk
EAPs developed with input from community members and stakeholders and emergency management agency and shared with selected community representatives	Community collaboration with owners or operators to develop integrated EAPs that reflect community values	Community collaboration results in EAPs that minimize consequences of defined emergencies by incorporating community values and the potential for community resilience
Floodplain management plans integrated into community comprehensive or general plans	Floodplain management plans fully integrated into dam and levee owners' planning processes	Full participation by both community and dam and levee owners in floodplain management facilitates adoption of complementary resilience-enhancing measures

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post-disaster recovery plans, or when to acquire or assist in the acquisition of land subject to deep flooding to prevent its development for urban uses. They may also be able to assist in arranging with financial institutions for low-cost loans to fund flood-proofing of residences and businesses, and with training and certifying remodeling companies to increase the supply of flood-proofing services.

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CHAPTER SIX

Conclusions

Collaborative efforts among community members and stakeholders more broadly are necessary to achieve a high level of resilience. Ideas need to be integrated and solutions implemented that meet community needs and address community-identified resilience goals. However, even members of the geographic community can have broad and sometimes competing interests, as well as different technical and nontechnical backgrounds that make communication difficult. The differences become even more pronounced when considering stakeholders from outside the geographic area. Even so, it is important to involve community members and stakeholders as main actors in enhancing resilience to gain trust and "buy-in" of resilience-enhancing processes. Hazards and risks need to be communicated by means that can be understood by all, which implies careful consideration of community factors to identify those means. The same means may not work for all groups.

The committee experienced communication problems similar to those described above, albeit on a smaller scale, during its own deliberations. As a diverse group of engineers, social scientists, community planners, and other experts, the committee had to learn to communicate to identify issues and a vision for incorporating concepts of community resilience into dam and levee safety programs. The committee quickly learned that individual members used different vocabularies to express themselves, complicating the sharing of ideas. As committee discussions progressed, members often recognized that their goals were not actually divergent. They found instead a common vision and a shared set of conclusions.

Similar challenges will present themselves to dam and levee safety professionals on a much greater scale as they attempt to engage the broader community in improving community resilience. Different groups will have different assumptions, perceptions, and vocabularies, which will make communication difficult—at least initially. But the experience of this committee suggests that progress can be made when individual and mutual needs and goals are identified and clearly stated.

The Maturity Matrix for Assessing Community Engagement (see Chapter 5) was first

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proposed in committee discussions as a means with which communities can assess the progress of safety programs along the continuum of resilience-enhancing efforts. But it became, quite unexpectedly, an effective tool for gauging committee progress in developing ideas and building consensus. The committee noted that simply discussing the elements of the maturity matrix allows those with different backgrounds (e.g., representing different stakeholder groups) to understand the many complex elements of dam and levee safety programs and community requirements for enhancing resilience. The committee came to understand how the Maturity Matrix for Assessing Community Engagement can be tailored to various scales of use and different organizational levels. With that tool to aid communication, the committee developed the set of conclusions summarized in this chapter.

Many conclusions appear throughout this report. This chapter presents those core conclusions related to the major cultural shifts the committee believes are necessary to integrate concepts of resilience into dam and levee safety programs. They appear in much the same order in which they became understood as vital during committee deliberations. The conclusions here begin with a definition of community, and continue with the identification of major inhibitors of resilience, the committee vision for the role of dam and levee safety programs in enhancing resilience, and finally conclusions related to how that vision can be realized and how the federal government might facilitate that realization. Conclusions related to specific tools that could be developed by the federal government to aid dam and levee safety programs related to identifying and engaging community members and stakeholders, and in decision making and decision support systems can be found in Chapter 5.

DEFINING COMMUNITY

> **Conclusion 1. The dam and levee community comprises dam and levee safety professionals, and other individuals, groups, and institutions that benefit from the continued and safe functioning of dam and levee infrastructure—whether or not those benefits are recognized by the individual community members.**

> **Conclusion 2. Community resilience is a community effort, and dam and levee safety professionals are part of the community.**

Community resilience, by its nature, is a community enterprise that requires the participation of all members and stakeholders. Dam and levee professionals (e.g., owners and operators, regulators, consultants, and emergency management officials) are members of the communities they serve. Other community members are those at direct risk for loss of life, limb, or property as a result of flooding from dam or levee failure; those who rely directly or indirectly on the lifeline services that a dam or levee may provide (such as drinking water or electricity); individuals and organizations at financial risk as a result of links to the regional,

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national, or global economies (such as shareholders, mortgage holders, and insurers); and individuals and organizations with ties to regional political and social networks through family, neighborhood, religious, or other networks, and those who benefit from affected environmental ecosystems. Because each community is unique, community members and stakeholders may not be easily divided into definitive categories.

Dam and levee professionals will serve their communities more successfully when they embrace the idea that "community," in the context of dam and levee safety, extends well beyond those in the inundation zone. Such a broad definition of community implies that risks and benefits associated with dam and levee infrastructure need to be evaluated on multiple scales without diminishing the role of the proximate community. Therefore, it is necessary to understand the complex social, economic, environmental, and other relevant networks that may be affected by failure. Global supply chains may be affected, and financial support networks of shareholders, mortgage providers, and insurance companies may suffer the direct or indirect consequences of flooding. Their losses may have cascading effects on the welfare of the local, regional, or global communities.

Conclusion 3. Those subject to the direct or indirect impacts of dam or levee failure are also those with the opportunity to reduce the consequences of failure through physical and social changes in the community, community growth planning, safe housing construction, financial planning (including bonds and insurance), and development of the capacity to adapt to change.

Members of a community, including dam and levee professionals, know more about their community than anyone else and therefore are in the best position to improve their community. Dam and levee safety professionals can provide critical expertise, support life-cycle hazard and risk assessments, and take part in informed decision-making processes as they and the broader community work to enhance resilience. At the same time, dam and levee professionals and the organizations they represent can ultimately derive benefits from participation in efforts to enhance community resilience, including a potential reduction in liability through decreased flood risk.

ENABLING INFORMATION ACCESS

Conclusion 4. Current policy and practices restrict access to information critical to public risk awareness, mitigation, preparedness, response, recovery, and community capacity for adaptation. Dam and levee safety processes and products (such as inspections, Emergency Action Plans [EAPs], and inundation maps) are intended to support decision making and enhanced community resilience,

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but are not readily available to all community members and stakeholders who make those decisions.

Decisions or practices intended to support national security, protect proprietary interests, or minimize liability concerns are often used as justification for not sharing information critical for informed decision making related to improving resilience. The lack or intentional withholding of vital information related to risk hampers community risk assessment, preparedness, mitigation, response, recovery, and capacity for adaptation, and may ultimately do more harm than good. Trust in dam and levee owners and government agencies may be diminished, and community members and stakeholders may be unaware of their exposure to flood risks. The ability to prepare for and respond to adverse events can therefore be compromised.

Dam and levee owners themselves could manage their responsibilities with a greater understanding of the upstream and downstream factors that influence risk. Communities as a whole could address risk better if consequences of various dam and levee failure scenarios were understood. Having the information needed to assess and manage risk associated with flood-water management, and having that information presented in understandable and actionable ways, is vital to the ability of the entire community to plan for and mitigate the direct and indirect consequences of infrastructure failure. Risks associated with national security hazards, proprietary interests, or liability protection need to be realistically compared with the risks associated with dam and levee infrastructure failure before making decisions to withhold risk information. In the absence of accurate inundation maps, for example, many rely on Federal Emergency Management Agency (FEMA) maps that do not depict the areal extent or severity of all flood risks, and insurers and financial institutions are forced to make decisions without knowing the aggregate risks they may be taking.

Dam safety professionals themselves have focused much of their effort on reducing the likelihood of flooding due to uncontrolled and controlled flow from dams and the development of EAPs. Levee safety professionals have been similarly concerned with preventing uncontrolled flow, although levee safety programs generally are far less mature than dam safety programs. Focus on EAPs is essential for both dams and levees, but EAP preparation is not an established practice for levee safety, and EAPs alone are not sufficient to enhance community resilience. The lack of availability of comprehensively prepared and disseminated EAPs, of detailed and accurate inundation maps, and of comprehensive public awareness programs compromises effective decision making conducive to enhancing resilience. The collaboration and two-way communication with local community officials that results from a robust EAP process generates opportunities to enhance resilience.

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MANAGING RISK COLLABORATIVELY

Conclusion 5. Enhancing resilience will be most successful when dam and levee safety professionals and other community members and stakeholders identify and manage risk collaboratively in ways that increase understanding and communication of risks, shared needs, and opportunities.

As members of the larger community, dam and levee professionals share opportunities and responsibilities with other community members to improve resilience associated with the primary and secondary effects of dam or levee failure. Likewise, involvement of the broader community brings expertise and resources that can benefit dam and levee professionals. Collaborative engagement builds the trust among dam and levee professionals and other community members that is a vital element of community resilience. With trust comes more effective communication, improvements in social capital, deeper appreciation of dam and levee infrastructure, and recognition of dam and levee professionals as good community citizens. Robust interaction also encourages comfort and familiarity in collaborative work, qualities that contribute to effective response during emergencies. Strangers working together for the first time during a crisis may be less effective than people who already have developed communication channels and trust.

Community resilience and traditional mitigation and emergency preparedness efforts will be improved if the key representatives of the entire community can be identified and engaged. Collaborative risk management can take many forms, and many models of resilience-focused collaboration are available for consideration—for example, Tulsa Partners,[1] Safeguard Iowa Partnership,[2] and Earthquake Country Alliance.[3] Collaborative management, however, is most effective when it is community based and managed by the community. Collaboration can begin with efforts to extend existing relationships that dam and levee professionals have with a community's appointed and elected officials, and through participation in existing resilience-focused partnerships in the community. The goal is to significantly expand and strengthen current interaction and engagement. In addition, there is a place at the table for federal partners in dam and levee safety at the community level, but their most effective role (if not the infrastructure owner) is facilitative—providing information and guidance—rather than prescriptive.

Making hazard information available to a wider audience will ensure that a greater number of community members and stakeholders understand the potential scenarios and risk exposure. This can lead to greater demand for engagement among all and ultimately to the development of physical, societal, and financial solutions for improving resilience.

[1] See tulsapartners.org/tpi/ (accessed February 17, 2012).
[2] See www.safeguardiowa.org/ (accessed February 17, 2012).
[3] See www.earthquakecountry.info/ (accessed February 17, 2012).

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Conclusion 6. Risk-informed approaches allow dam and levee professionals to improve their understanding of infrastructure-system operations, performance, vulnerabilities, and the consequences of potential failures, and allow them and the broader community to make better decisions related to dam and levee infrastructure and resilience.

Current dam and levee engineering design and operating procedures are largely standards-based, and uncertainties associated with hazards and structural or system performance are largely ignored. Conventional engineering practices obscure a full understanding of risk. Until recently, even discussing how a system might fail was not a part of dam and levee engineering culture. Although there has been a trend toward more risk-based approaches to dam and levee safety evaluation in recent years, the use of these approaches is not universal and is far from mature in the profession. Expanding dam and levee safety practice to include collaborative risk management implies the need to communicate the benefits and risks associated with dam and levee infrastructure to the community. Doing that implies a need to understand and quantify associated risks and consequences as fully as possible, not only for the benefit of the dam or levee owner but also for the broader community. The ability to understand and respond to potential consequences is essential for enhancing resilience.

Deterministic approaches (e.g., probable maximum flood and standard project flood approaches) focus only on what is assumed to be the worst possible scenario for a given hazard without consideration of the likelihood of the event and without understanding the accuracy of the predicted scenario. Risk-based methods, in contrast, allow evaluation of the likelihood of events in a broad array of scenarios and allow prediction of the types and magnitudes of consequences associated with those scenarios. Risk-based, or at least risk-informed approaches contribute to more open, honest communication of community exposure to adverse events, even given uncertainties in current approaches. Such communication contributes to collaborative processes significantly and can be an agent of change on the part of policy makers and the broader public. It allows communities to appreciate the benefits of dam and levee infrastructure, understand different stakeholders' risks associated with their operation and potential failure, and make appropriate decisions to improve dam and levee safety, reduce flood risk and associated liabilities for different groups at risk, and increase community resilience.

MAKING A CULTURAL SHIFT

Conclusion 7. Improving dam and levee safety programs to emphasize processes that enhance community resilience requires a culture shift among dam and levee professionals. This new emphasis requires embracing the responsibilities—and

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the benefits—associated with developing and implementing collaborative risk-management processes that facilitate enhanced community resilience.

Dam and levee safety programs have improved substantially in recent decades, but they remain focused on regulatory compliance, on preventing failures, and on elements of emergency preparedness. Regulatory compliance is a necessary first step, but it alone will not build community resilience. The vision for future dam and levee safety programs is one in which dam and levee safety professionals and the larger community are active participants in risk-informed processes that support improved community resilience. Future dam and levee safety programs will continue their mitigation and emergency preparedness efforts, but a clearer understanding and communication of risks will be required, as will broader engagement with community members and stakeholders in which two-way communication of individual and common needs is the norm. It is such communication and engagement that allow resilience-enhancing processes to be identified and implemented. Such a future is achievable, but only in the context of changes in the traditional culture of dam and levee communities and in the public's view of these systems.

This vision is applicable to both public- and private-sector dam and levee safety programs, and both will need to overcome obstacles. Public-sector dam safety programs, for example, often do not have the funds to meet mandated responsibilities. Jurisdiction over levees is often unclear, so it may be difficult to determine who has the responsibility and legal authority to affect change. The lack of data that are readily available to community members and stakeholders outside dam and levee professional networks hampers community understanding of risk, or even the recognition of being at risk, and constitutes a barrier to change. Cultural change at the dam and levee program level will be more likely if there are commensurate changes in state legislatures, in Congress, in dam and levee owner management or board rooms, and among dam and levee engineers themselves. Support is needed to expand the scope of dam and levee safety programs so they can contribute to enhancing and sustaining community resilience.

Activities to enhance community resilience with respect to dam and levee safety need not and should not be separate from broader community resilience efforts. It is the responsibility of dam and levee professionals at all levels (local through federal) to bring their unique expertise to bear and to assist their programs in putting into place the processes needed to assess and address community resilience related to dam- and levee-associated risk.

A REPOSITORY OF RESILIENCE-ENHANCING TOOLS

Conclusion 8. The federal government can aid resilience-enhancing efforts by identifying, cataloging, further developing, communicating, and facilitating the use of tools and guidance that already exist in the published literature and in

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federal and state guidelines. Many existing tools may need little or no modification to be useful for enhancing community resilience for specific situations. Cataloging existing tools is a first step in identifying and setting priorities for developing necessary new tools.

The availability of dam and levee information supports a community's ability to remain informed about dam and levee infrastructure benefits and risks, operations, potential for failure, and procedures in place to prepare, mitigate, respond and recover from and adapt in response to potential failure. Such information is vital to the decision making that makes communities more resilient. However, dam and levee safety programs and communities may not know how best to determine the reliability and usefulness of information and data, or how to communicate them in efficient, timely, and actionable ways. Enhancing resilience requires an understanding of what resilience is. Resilience can be defined and understood only in the context of the individual community because each community faces different risks and has unique requirements for continued successful functioning. Successful practices of similar communities (e.g., best practices) can be shared through federal communication mechanism (such as FEMA's long-term recovery support arm, Emergency Support Function 14).[4]

The federal government contributes to community-level resilience best when it contributes in a supportive role—in this case through the provision of information, guidance, and tools for dam and levee professionals and other relevant community members and stakeholders. The tools provided cannot be one-size-fits-all, given the uniqueness of communities. Those made available must be flexible to assist decision making and must provide the right level of analysis for state and local application. It would be worthwhile for federal agencies that have roles in dam and levee safety, in collaboration with states and representative owners, to review their own processes for enhancing community safety and resilience. They could determine what tools and resources exist and are still needed to be most helpful in facilitating local resilience-building efforts. The next step would be to determine the best way to make those tools available to local dam and levee safety programs and the communities they serve. Exploring effective incentives for their use would also be appropriate.

A number of federal agencies are putting forth effort with respect to enhancing community resilience. These efforts may focus on all-hazards approaches to enhance community resilience; risks associated with dam and levee failure may be among the hazards (see, e.g., the FEMA Risk MAP program).[5] Tools, guidance, and best practices for enhancing resilience may have already been described in programs of those or other agencies.

[4]See www.fema.gov/rebuild/ltcr/plan_resource.shtm (accessed February 19, 2012).
[5]See www.fema.gov/plan/prevent/fhm/rm_main.shtm (accessed February 19, 2012).

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INSTITUTIONALIZING RESILIENCE PROCESSES

Conclusion 9. Collaborative efforts that become a normal part of community functioning will enhance resilience more successfully in the long term. Continuous improvements in community resilience are more likely if such processes as community and stakeholder engagement assessment are institutionalized by dam and levee safety programs and the broader community.

Enhancing resilience is a multistage process that encompasses efforts to identify and reduce risks, prepare for hazardous events, respond to and recover from events, and allow community adaptation in response to lessons learned from the entire cycle of activities. Without a continuous effort to sustain an environment conducive to enhancing resilience, these efforts and their beneficial outcomes will be short-lived. A successful program includes long-term planning in which life-cycle benefits and costs of dam and levee infrastructure are widely understood by the community. Successful efforts, therefore, will be ones that are institutionalized in dam and levee safety programs and the broader community, that build the trust that allows effective collaboration, and that encourage active engagement. When safety programs integrate the assessment of engagement into their long-term management, benchmarking of processes and identification of opportunities to improve community resilience will become part of the operational norm. Efforts to do so will build important relationships among community members and stakeholders, including dam and levee professionals. This social capital—manifested as effective working relationships—will be the underpinning of community resilience.

BENCHMARKING PROGRESS IN SAFETY AND ENGAGEMENT

Conclusion 10. Enhancing resilience requires frequent and collective evaluation of risk, safety, and collaborative processes. The proposed Maturity Matrix for Assessing Community Engagement can be used by dam and levee safety professionals, community members and stakeholders, and government entities at all levels to benchmark and manage the progress of industry and community processes related to safety and engagement. Details of assessment are necessarily unique for each community. The federal government can assist communities by providing an initial framework for the assessment tool, and providing information and training for its development and continued use at the community level.

Enhancing resilience requires evaluation of the overall posture of a community with respect to resilience. Tools for measuring resilience directly, however, do not exist. In their absence, adequate evaluation requires some method for capturing and assessing resilience-

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improving processes that a community has in place. A rubric for such assessment is needed. The Maturity Matrix for Assessing Community Engagement (see Chapter 5 for detailed description) can help dam and levee professionals and the broader community to gauge the level of practice with respect to community resilience and to understand how individual processes fit into the larger community resilience picture. The use of the assessment tool allows communities to become familiar with resilience-building processes already in place, to determine goals and priorities for improvement, to identify processes needed to meet those goals, and to monitor outcomes of other tools and programs in place in the community.

The Maturity Matrix for Assessing Community Engagement, as envisioned by the committee, depicts different aspects of dam and levee infrastructure operations and community processes to which dam and levee professionals may be able to contribute (see Figure 5.2). The maturity matrix is necessarily unique to the community it serves just as what defines community resilience is individual to the community; a matrix developed for one community may not be adequate for another. The matrix captures the continuous improvements necessary for designated processes to reach safety- and resilience-related goals at different stages of development. Already, a best practice of dam and levee owners is to identify potential and actual deficiencies of their facilities through periodic assessments. The Maturity Matrix for Assessing Community Engagement allows dam and levee owners and the broader community to visualize the status of any number of detailed processes on a continuum and provides a roadmap for planning that allows all to be mindful of the tension between budgetary constraints and community goals.

Active engagement is vital, and the development of a maturity matrix provides a mechanism for promoting two-way communication between dam and levee professionals and the broader community. Early collaborative efforts, for example, could include discussion of a single element of the matrix. Deciding on goals, processes, and what constitutes progress creates a means of building social capital. Dam and levee owners and members of the broader community will need assistance in customizing the matrix and using the tool to its fullest potential for assessment of practice over time.

The federal government could develop a basic framework for the Maturity Matrix for Assessment of Community and Community and Stakeholder Engagement (recognizing that the matrix must be customized and fully developed at the community level) and for the training necessary to institutionalize its use in any safety program. Because the assessment tool is scalable and can be readily modified to assess the progress of a large variety of resilience-related activities, programs, or types of infrastructure at various levels (local, state, regional, and national), it may also be worthwhile to explore its use more generally to aid in identifying

- characteristics of resilience in individual communities (or organizations or regions) and the objectives that need to be reached to make them more resilient;

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- methods and strategies for identifying stakeholders, engaging in resilience-focused collaboration, and communicating risk in clear, understandable, and actionable terms;
- vulnerabilities and risks associated with all hazards and potential alternatives for reducing or mitigating them;
- roles of community factors (such as legislation and land-use planning) in the severity of the hazards.

Once developed sufficiently as a tool, the federal government could facilitate a pilot program in a community to demonstrate the tool's usefulness.

MOVING FORWARD

In keeping with its task, the committee presents a means of improving and expanding dam and levee safety programs into programs that integrate processes that promote community resilience into daily safety practice. The committee offers a fundamental framework for a holistic and systematic approach to safety analysis that incorporates elements of community resilience and risk management. If developed and tailored to applications in individual community or safety programs, the framework would likely improve communication, allow communities to establish goals and priorities, and identify the means to reach goals to improve resilience.

Moving forward with the suggestions in this report is a major undertaking that will require the efforts of more than one entity, more than one piece of legislation, or a single source of funding. It will require many individuals in a community to evolve their thinking about resilience and their roles in enhancing resilience. Dam and levee professionals, and engineers in particular, will need to expand their safety practices and align them to be consistent with concepts of community resilience. This will, in many cases, conflict with long-held traditions in training and practice. The course of action suggested by the committee is game-changing and perhaps not welcome by many in this time of limited resources and budget cuts. However, in the context of long-term land-use and floodplain management, and considering the life cycles of the critical infrastructure involved, the expenditures will prove worthwhile.

An incremental approach will be necessary to make the changes suggested, but each increment should be a step toward community agreed-on outcomes. Once the approach suggested in this report is accepted by a safety program—whether public or private, and whether at the local, state, regional, or national level—it will be incumbent on the program, with the assistance of those at higher levels, to determine how to make the approach fit its unique circumstances. Given that the maturity matrix is scalable, a matrix established for a program may be broken down and detailed to address the responsibilities of the geotechni-

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cal, geologic, hydrologic, hydraulic, and civil or structural elements of the safety program. Doing so will ensure that the entire program is making design and operational decisions consistent with safety and community priorities for resilience.

The committee has focused largely on the concept of community and stakeholder engagement and the assessment of progress of engagement in advancing community resilience goals. The Maturity Matrix for Assessing Community Engagement can be central to both. Engagement, however, cannot substitute improved dam and levee infrastructure integrity and technical decision making, nor can it substitute adequate resource allocation for said improvements. It can, however enable effective two-way communication coupled with risk-based safety analysis and enable communities to use its resources more effectively to mitigate, prepare for, respond to, and recover and learn from dam and levee failure. The active engagement it encourages may facilitate common understanding of how local events or choices have impacts beyond the local community, and may help communities identify common and conflicting priorities among its local, regional, and even global members. Further, it can inform technical decision making to improve infrastructure integrity as well as strengthen a community's ability to influence policy in positive ways. Many of the principles developed in this report are applicable not only to resilience associated with dam and levee infrastructure but to resilience associated with other types of critical infrastructure, and to disasters in general.

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List of Acronyms

ASCE	American Society of Civil Engineers
ASDSO	Association of State Dam Safety Officials
ASFPM	Association of State Floodplain Managers
CA DWR	California Department of Water Resources
CMMI	Capability Maturity Model Integration
DEFRA	Department for Environment, Food and Rural Affairs
DHS	U.S. Department of Homeland Security
DOI	U.S. Department of the Interior
DSAC	Dam Safety Action Classification
EAP	Emergency Action Plan
FEAT	Flood Emergency Action Team
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FIFM-TF	Federal Interagency Floodplain Management Task Force
GEMA	Georgia Emergency Management Agency
ICODS	Interagency Committee on Dam Safety
IPET	Interagency Performance Evaluation Taskforce
IPOC	Independent Panel of Consultants
IRRM	Interim Risk Reduction Measure

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LEED	Leadership in Energy and Environmental Design
NAFSMA	National Association of Flood and Stormwater Management Agencies
NASA	National Aeronautics and Space Administration
NCLS	National Committee on Levee Safety
NDSP	National Dam Safety Program
NFIP	National Flood Insurance Program
NID	National Inventory Dams
NLD	National Levee Database
NPDP	Stanford University National Performance of Dams Program
NRC	National Research Council
NDSRB	National Dam Safety Review Board
OPG	Ontario Power Generation
PFMA	Potential Failure Mode Analysis
RESTORE	Rivers: Engaging, Supporting and Transferring Knowledge for Restoration in Europe
SEI	Software Engineering Institute
SLFPAE	Southeast Louisiana Flood Protection Authority—East
SPF	Standard Project Flood
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNISDR	United Nations International Strategy for Disaster Reduction
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USCOLD	U.S. Committee on Large Dams
USGS	U.S. Geological Survey
USSD	U.S. Society on Dams
VT DEC	Vermont Department of Environmental Conservation
WMO	World Meteorological Organization
WRC	Water Resources Council
WRDA	Water Resources Development Act

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Appendixes

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APPENDIX A

Committee Biographies

John Boland (*Chair*) is a professor emeritus in the Department of Geography and Environmental Engineering and Program Chair for Environmental Sciences in the Advanced Academic Programs, both at Johns Hopkins University. His fields of research include water and energy resources, environmental economics, and public utility management. Dr. Boland has studied resource problems in more than 20 countries, has published more than 200 papers and reports, and is a coauthor of two books on water demand management and three others on environmental management. He has served on several National Research Council committees and boards, most recently on the Committee on Louisiana Coastal Protection and Restoration, and is a founding member and past chair of the Water Science and Technology Board. Dr. Boland is a registered professional engineer, and a life member of the American Water Works Association and past chairman of its Economic Research Committee. Dr. Boland received his Ph.D. in environmental economics from Johns Hopkins University.

Tony Bennett is the director of dam safety and emergency preparedness for Ontario Power Generation and serves on a number of committees and panels in Canada that are related to dam safety. His expertise is in dams and reservoir operations. He is the president of the Engineering Institute of Canada, chair of the International Commission on Large Dams Committee on Public Safety Around Dams, and chair of the Canadian Dam Association Working Group on Public Safety Around Dams. He is a member of the Government of Ontario advisory panel that is developing regulations and technical guidelines for dam safety. Mr. Bennett recently completed an 8-year term with the Canadian Dam Association and served as its president during 2006–2008. He graduated with an Honours Bachelor of Applied Science in Civil Engineering degree and is a registered professional engineer in Ontario, Canada.

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Raymond J. Burby is a professor emeritus in the Department of City and Regional Planning at the University of North Carolina at Chapel Hill. Dr. Burby is a fellow of the American Institute of Certified Planners. He has been an author or editor of 14 books and has published extensively in planning and policy journals, including the *Journal of the American Planning Association*, the *Journal of Planning Education and Research*, the *Journal of Policy Analysis and Management*, and the *Journal of Environmental Planning and Management*. He is principal investigator in a study of urban growth boundaries funded by the National Science Foundation (NSF) and in another NSF-funded project designed to improve the quality of applied research on disasters and mitigation of natural and technological hazards. He received his Ph.D. in planning from the University of North Carolina at Chapel Hill.

Stephen J. Burges is a professor emeritus of civil and environmental engineering at the University of Washington, Seattle, where he spent his professional career. Dr. Burges's research interests are in surface-water hydrology; urban hydrology; water-supply engineering; the application of stochastic methods in water resources engineering; water resources systems design, analysis, and operation; water resources aspects of civil engineering; and groundwater hydrology. He is a fellow of the American Society of Civil Engineers (ASCE), the American Association for the Advancement of Science, and the American Geophysical Union (AGU). He is a past president (1994–1996) of the hydrology section of AGU. He has presented the Langbein Lecture for AGU, and is the recipient of the Ray K Linsley Award of the American Institute of Hydrology, and the Ven Te Chow Award of ASCE. Dr. Burges was a member of the National Research Council Water Science and Technology Board from 1985 to 1989. He received a B.Sc. in physics and mathematics and a B.E. (Hons 1) in civil engineering from the University of Newcastle, Australia, in 1967. He received an M.S. in 1968 and a Ph.D. in 1970 in civil engineering from Stanford University.

Rita E. Cestti is a senior rural development specialist in the Quality Assurance and Compliance Unit at the World Bank. She has managed the identification, preparation, and supervision of a number of water-related, natural resources, environmental, and disaster management projects in several countries and has led the preparation of several pieces of economic-sector work and implementation of technical assistance activities. She has conducted extensive economic studies in the context of sector work and project analysis and in-depth research in the economics of water resources management and development, demand management, water allocation, water pricing, water pollution control, and integrated planning. She holds a B.S. and a professional degree in civil engineering from the Pontificia Universidad Católica, Peru, and an M.S. in engineering administration and M.A. in economics from the George Washington University. She is a registered professional civil engineer in Peru.

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Ross B. Corotis (NAE) is the Denver Business Challenge Professor of Engineering at the University of Colorado at Boulder and has research interests in the application of probabilistic concepts and decision perceptions for civil engineering problems, in particular societal tradeoffs for hazards in the built infrastructure. His current research emphasizes the coordinated roles of engineering and social science with respect to framing and communicating societal investment for long-term risks and resilience. He was on the faculty of Northwestern University for 11 years; established the Department of Civil Engineering at Johns Hopkins University, where he was associate dean of engineering; and was dean of the College of Engineering and Applied Science in Boulder. He has received numerous research, teaching, and service awards; chaired several committees on structural safety for the American Society of Civil Engineers (ASCE) and American Concrete Institute; was editor of the international journal *Structural Safety* and the ASCE *Journal of Engineering Mechanics*; and chaired the Executive Committee of the International Association for Structural Safety and Reliability. He has served on the National Academies Building Research Board and the steering committee of the Disasters Roundtable and chaired the Assessment Panel for the NIST Building and Fire Research Laboratory. He is the founding chair of the Committee on NIST Technical Programs and Chair of the Civil Engineering Section of the National Academy of Engineering. He is the author of more than 200 publications. Dr. Corotis received his S.B., S.M., and Ph.D. in civil engineering from the Massachusetts Institute of Technology.

Clive Q. Goodwin is assistant vice president and manager of natural-hazard peril underwriting for FM Global, an insurance company in Johnston Rhode Island that provides global commercial and industrial property insurance, engineering-driven underwriting, and risk management solutions. In this position, he manages worldwide underwriting of wind, flood, and collapse perils. This involves developing and maintaining strategies to capitalize on FM Global's engineering knowledge of natural hazards to benefit clients with respect to risk improvement and insurance terms and conditions. Before accepting his current appointment in 2007, he served as assistant vice president and manager of natural-hazards engineering. Mr. Goodwin has held several engineering positions in the UK, the Netherlands, and the United States since joining FM Global in 1988 as a field engineer. Recently, he was the leader of FM Global's efforts to collaborate with the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, and other agencies to highlight concerns regarding the aging inventory of levees while supporting their efforts to change U.S. national policy concerning the levee risk. Mr. Goodwin holds a B.Sc. in mechanical engineering and metallurgy from the University of Manchester Institute of Science and Technology, Manchester, UK, and a certified diploma in accounting and finance. He is also a chartered engineer and a member of the Institution of Mechanical Engineers and has served on the Industry Leaders Council of the American Society of Civil Engineers.

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Roger E. Kasperson (NAS) is a research professor and distinguished scientist at the George Perkins Marsh Institute of Clark University. He has taught at Clark University, the University of Connecticut, and Michigan State University. His expertise is in risk analysis, global environmental change, and environmental policy. Dr. Kasperson is a fellow of the American Association for the Advancement of Science and the Society for Risk Analysis. He has served on numerous National Research Council committees. He chaired the International Geographical Commission on Critical Situations/Regions in Global Environmental Change and has served on the Environmental Protection Agency's Science Advisory Board. He now serves on the National Research Council Committee on the Human Dimensions of Global Change, is cochair of the Scientific Advisory Committee of the Potsdam Institute for Climate Change, and is on the Executive Steering Committee of the START Programme of the IGBH. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences. He is the author or coeditor of 22 books and monographs and more than 143 articles or chapters in scholarly journals or books and has served on numerous editorial boards of scholarly journals. From 2000 to 2004, Dr. Kasperson was executive director of the Stockholm Environment Institute in Sweden. He was a coordinating lead author of the vulnerability and synthesis chapters of the *Conditions and Trends* volume of the Millennium Ecosystems Assessment and a member of the core writing team for the synthesis of the overall assessment. Dr. Kasperson has been honored by the Association of American Geographers for his hazards research and in 2006 was the recipient of the Distinguished Achievement Award of the Society for Risk Analysis. In 2007, he was appointed associate scientist at the National Center for Atmospheric Research in the United States. He received his Ph.D. from the University of Chicago.

Shirley Laska is professor emerita of sociology and past director of the Center for Hazards Assessment, Response and Technology at the University of New Orleans (UNO-CHART). She has been conducting applied research on the social–environmental interface, natural and technologic hazards, and disaster response for 25 years. Dr. Laska's work includes studies on residential flood mitigation, hurricane response, coastal land-loss effects, coastal fisheries, community risk assessment and risk management for coastal hazards, use of information technology and GIS as support tools for disaster management, and evacuation of the vulnerable. She has presented her work at National Academies conferences and congressional committees. Since Hurricane Katrina, Dr. Laska's work has been focused specifically on lessons to be learned from the event, especially in the realm of community recovery and hazard resilience. This work emphasizes participatory action research in both slow-onset events (coastal land loss and sea-level rise) and abrupt major disaster events (Hurricane Katrina and the BP oil leak). She is the 2008 recipient of the American Sociological Association (ASA) Public Understanding of Sociology Award for her continuous collaboration with physical scientists and her presentations nationwide on impacts of Hurricanes Katrina

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and Rita, and awards from the ASA Environment and Technology Section and the Rural Sociological Society's Natural Resources Research and Interest Group. Dr. Laska earned her Ph.D. in sociology from Tulane University.

Lewis E. Link is a senior fellow in the R.H. Smith School of Business and a senior research engineer in the Department of Civil and Environmental Engineering of the University of Maryland. Dr. Link was a senior executive in various research and development positions in the U.S. Army Corps of Engineers from 1986 to 2002, rising to the position of director of research and development. Dr. Link's principal work is in water resources management and natural-disaster mitigation. He has published numerous papers on water resources–related remote sensing and water policy and on natural-hazard mitigation. Dr. Link served as the director of the Interagency Performance Evaluation Task Force charged with providing scientific and engineering answers to questions about the performance of the New Orleans and Southeast Louisiana Hurricane Protection System during Hurricane Katrina, and he was the recipient of the McGraw-Hill *Engineering News-Record* Award of Excellence in 2006 for leading the forensic analysis of Hurricane Katrina. Dr. Link received his B.S. in geological engineering from North Carolina State University, his M.S. in civil engineering from Mississippi State University, and his Ph.D. in civil engineering from Pennsylvania State University.

Martin W. McCann, Jr., is president of Jack R. Benjamin & Associates, Inc., and is a consulting professor of civil and environmental engineering at Stanford University, where he is the director of the National Performance of Dams Program. His expertise and professional experience include probabilistic risk analysis for civil infrastructure facilities and probabilistic hazards analysis, including seismic and hydrologic events, reliability assessment, risk-based decision analysis, systems analysis, and seismic engineering. Currently, Dr. McCann is the project technical manager of the Delta Risk Management Strategy project that is conducting a risk analysis for over 1,100 miles of levee in the Sacramento and San Joaquin Delta. He is also a member of the U.S. Army Corps of Engineers Interagency Performance Evaluation Task Force IPET Risk and Reliability Team, which is evaluating the risk associated with the New Orleans levee protection system. Dr. McCann received his B.S. in civil engineering from Villanova University in 1975, his M.S. in civil engineering in 1976 from Stanford University, and his Ph.D. in 1980 from Stanford University.

Hillman Mitchell is the King County (Washington) director of emergency management. Mr. Mitchell oversees a budget of $23 million and supervises employees at the Emergency Communications and Coordination Center in King County and the Emergency 9-1-1 office. The Office of Emergency Management works in partnership with cities, counties, state and federal agencies, and community and other private organizations to develop a

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regional approach to disaster mitigation, preparedness, response, and recovery related to hazards, including those associated with dam failure (including potential failure of the federally owned Howard Hanson Dam and 86 other dams in the county), flooding, landslides, earthquakes, tsunamis, volcanic eruptions, and other events. Before joining King County government, he worked as the City of Tukwila (Washington) emergency management coordinator and was well known to many county employees and regional emergency managers for his outstanding work with Tukwila and in his previous role as government liaison specialist for the American Red Cross. Previously, Mr. Mitchell ran a business as a developer of component software for the digital imaging industry, spent 5 years as a managing consultant at Microsoft, and provided direct technical management to a more than 40-member team of people worldwide as a senior computer scientist for DuPont/Conoco Research. Mr. Mitchell earned his bachelor's degree in management science and computer systems from Oklahoma State University and has done postgraduate work at the University of Denver, Colorado University, and Colorado State University in finance, communications, project management, and process management.

STAFF BIOGRAPHIES

Sammantha L. Magsino is a Senior Program Officer with the National Research Council's Board on Earth Sciences and Resources. She was previously a geologist with the Washington State geologic survey where she produced earthquake hazard maps and served as a technical advisor to the state on volcanic hazards. She also served as the science coordinator for a National Science Foundation facility at The University of Texas at Austin conducting aerogeophysical surveys in Antarctica, and has worked for the Center for Nuclear Waste Regulatory Analyses at the Southwest Research Institute conducting geophysical investigations near the proposed Yucca Mountain Nuclear Waste Facility in support of volcanic hazard assessment. Ms. Magsino holds M.S. and B.S. degrees in geology from Florida International University.

Jason R. Ortego was a research associate with the Board on Earth Sciences and Resources. He received a B.A. in English from Louisiana State University in 2004 and M.A. in international affairs from George Washington University in 2008. He began working for the National Academies in 2008 with the Board on Energy and Environmental Systems, and in 2009 he joined the Board on Earth Sciences and Resources.

Chanda Ijames is senior program assistant with the Board on Earth Sciences and Resources at the National Academies. She received a B.S. in Psychology from the University of Maryland University College and is pursuing an M.Ed. in Instructional Technology from University of Maryland University College. She began working for the National Academies, Board on Earth Sciences and Resources in 2011.

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APPENDIX B

Meeting Agendas

Boxes B.1 and B.2 are the open session meeting agendas for the Committee on Dam and Levee Safety and Community Resilience. Committee members gathered data through presentations from numerous individuals who represent various sectors within the dam and levee industry. Presenters addressed issues such as the regulations, guidance, standards, historical dam and levee performance, and current safety practice for committee members.

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Box B.1
Meeting 1 Agenda—Thursday, March 10, 2011
(Conference Center, Washington, D.C.)

9:00 a.m.	**Welcome, introductions,** *Dr. John Boland,* Committee Chair
9:05	**Sponsor expectations,** *Dr. Sandra Knight,* Deputy Associate Administrator for Mitigation, FEMA
9:30	Break
9:45	**Panel discussion—Why do we need this study?** *Mr. James Gallagher, Jr.,* New Hampshire Department of Environmental Services *Ms. Yazmin Seda-Sanabria,* USACE Critical Infrastructure Protection and Resilience Program *Mr. Steve Verigin,* GEI Consultants
11:45 a.m.	**Working lunch—**Continuation of Discussion
12:30 p.m.	**End open session**

Box B.2
Meeting 2 Agenda—Thursday, May 5, 2011
(Arnold and Mabel Beckman Center, Irvine, CA)

9:00 a.m.	**Welcome,** *John Boland,* Committee Chair Introductions, brief discussion of session goals **Speakers** *Mr. Kurt Rinehart, P.E.,* Miami (Ohio) Conservancy District *Dr. Dennis Mileti,* Department of Sociology, University of Colorado *Mr. Ricardo Pineda, P.E.,* California Department of Water Resources
Noon	**Working Lunch**
1:00 p.m.	**End of Open Session**

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APPENDIX C

Laws, Policies, and Guidelines Driving Dam and Levee Safety in the United States

This appendix provides some details of laws, policies, and guidelines that have driven dam and levee safety policy in the United States. Principal laws and policies that shape the governance of dam safety in the United States are provided in a simplified chronologic list in Table C.1. Table C.2 is a similar list of laws and policies that shape the governance of levee safety in the United States; it includes only what the committee interpreted as defining statutes.

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TABLE C.1 Principal Laws and Policies Shaping Dam Safety Governance

Date	Law or Mandate	Relevance	Policy and Programs Enabled
1917	Flood Control Act	First major flood legislation	Dealt primarily with levees on the Mississippi and Sacramento Rivers
1928	Flood Control Act Expanded	Extended 1917 act to include control mechanisms	Policy extended to include floodways, spillways, and channels; provided foundation for dam safety legislation
1972	33 USC 467: National Dam Safety Act	Authorized national inspection of dams	U.S. Army Corps of Engineers tasked with inventorying and inspecting dams
1977	Department of Energy Organization Act	Established Department of Energy and Federal Energy Regulatory Commission (FERC) from Federal Power Commission	FERC licenses and inspects nonfederal hydroelectric projects
1979	Executive Order 12148	Created Federal Emergency Management Agency (FEMA); required federal agencies to implement federal guidelines for dam safety	Guidelines for dam safety management
1986	Water Resources Development Act	Authorized National Dam Safety Program under secretary of the Army	Established National Dam Safety Review Board, National Inventory of Dams, and state assistance
1996	Water Resources Development Act, Pub. L. 104-303, § 215, National Dam Safety Program Act	Reauthorized National Dam Safety Program under FEMA	Granted assistance to states for research and training; expanded National Dam Safety Review Board
2002	PL 107-310: Dam Safety and Security Act	Reauthorized National Dam Safety Program and added national-security considerations	Failed to provide funding for repair and rehabilitation
2006	PL 109-460 National Dam Safety Program Act	Reauthorized National Dam Safety Program	

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TABLE C.2 Principal Laws and Policies Shaping Levee Safety Governance

Date	Law	Relevance	Policy and Programs Enabled
1917	Flood Control Act	First major flood legislation—Mississippi and Sacramento Rivers	Dealt primarily with levees
1928	Flood Control Act Expanded	Extended 1917 act to include control mechanism	Extended policy to include floodways, spillways, and channels
1936	Flood Control Act	Declared flood control a federal interest and vested authority in U.S. Army Corps of Engineers (USACE)	Levees along main stem of Mississippi become federal
1955	Pub. L. 84-99: Flood Control and Coastal Emergencies Act	Directed USACE to provide emergency repair or rehabilitation of federally authorized flood control works	
1968	National Flood Insurance Act	Authorized National Flood Insurance Program	Levees became part of the equation for flood insurance
1994	National Flood Insurance Reform Act	Prevented loans from federal agencies and programs for property in specific flood hazard areas	Placed some accountability in insurance program
2005	Pub. L. 109-148: National Levee Data Base Authority	Authorized national levee inventory and database	Interagency Levee Policy Review Committee established by Federal Emergency Management Agency (FEMA); USACE initiated levee inventory
2007	Pub. L. 110-114: WRDA, National Levee Safety Program Act	Established National Levee Safety Program (oversight by FEMA) and National Committee on Levee Safety (NCLS, chaired by USACE)	Mandated that NCLS develop a National Levee Safety Policy

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