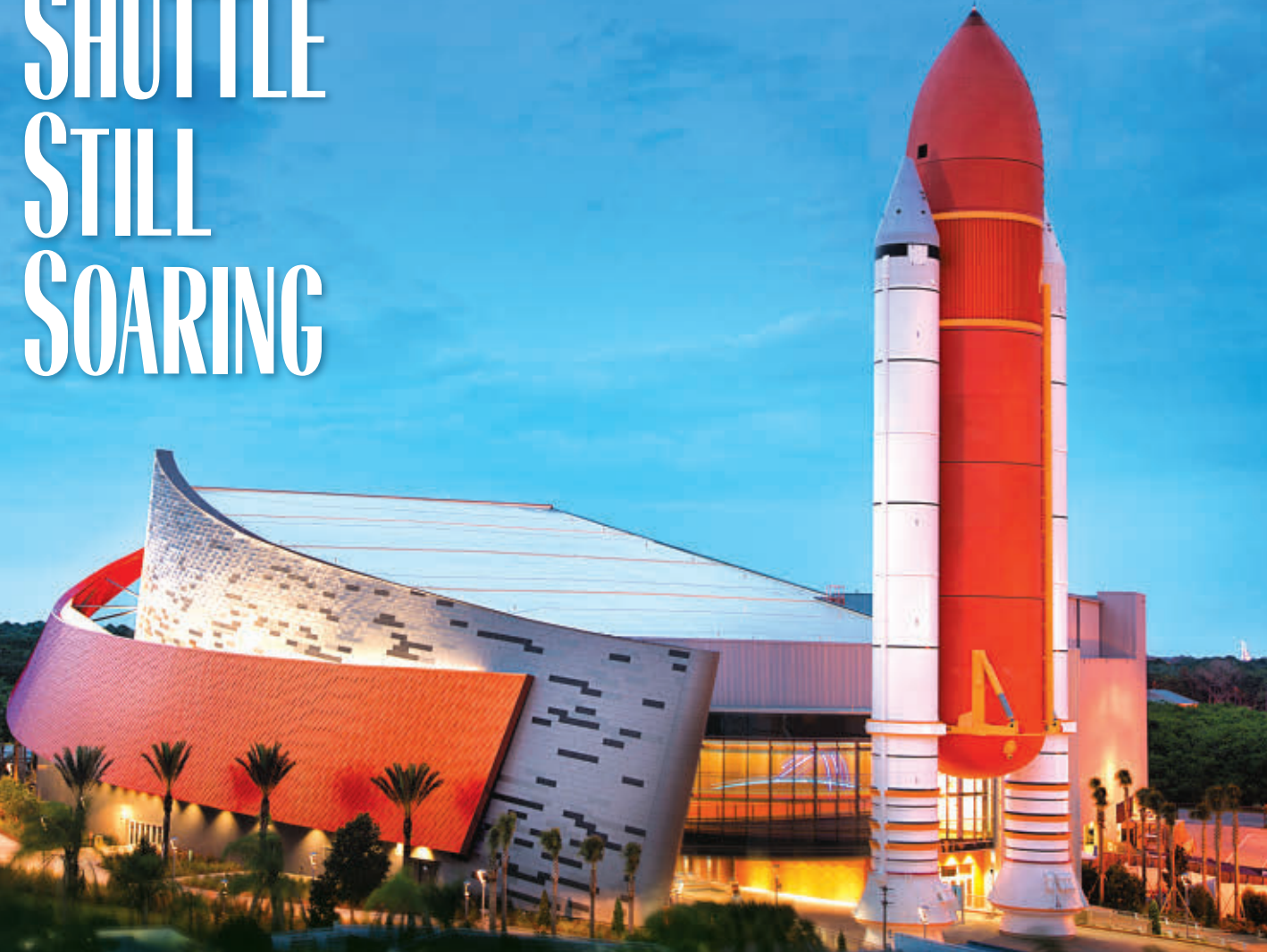


Civil Engineering

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SHUTTLE STILL SOARING



ALSO:

MANAGING FLOOD RISK

REPLACING AN AGING BRIDGE

**REHABBING SUBSURFACE
STRUCTURES**

A LARGE PORTION OF THE DESTRUCTION from Hurricane Katrina in 2005 was caused not only by the storm itself but also by the storm's exposure of engineering and engineering-related policy failures. ASCE's Hurricane Katrina External Review Panel, which was convened at the request of Lieutenant General Carl A. Strock, P.E., M.ASCE, then the commander and chief engineer of the U.S. Army Corps of Engineers, to conduct an in-depth peer review of the comprehensive work of the Corps's Interagency Performance Evaluation Task Force, published its report, entitled The New Orleans Hurricane Protection System: What Went Wrong and Why, in May 2007. In January 2012 ASCE's Board of Direction established the Task Committee on Flood Safety Policies and Practices (TCFSPP) to examine the findings put forth in the report, to determine whether progress has been made in implementing the calls for action included in this report, and to determine if the American public is now safer from the dangers of flooding. This article is a distillation of the TCFSPP's report, which will be published by ASCE later this year.

AMONG THE GREAT challenges the United States faces today is recognizing the magnitude of risk posed by flooding and motivating the public and decision makers to make the investments required to reduce flood risk, including making emergency preparations, strengthening our flood protection systems, or finding new ways to reduce our vulnerability to flooding.

More than eight years ago, in the wake of Hurricane Katrina's devastation of the U.S. Gulf Coast, ASCE issued a call for action urging the nation to address the growing challenge of increasing flood losses in the United States and the threat to the safety of the populations living in the paths of such events. Similar reports have been issued by both governmental and nongovernmental organizations since Katrina, and they have echoed ASCE's call.

Over the course of the past year, ASCE's Task Committee on Flood Safety Policies and Practices (TCFSPP) examined our national response to this call for action. This committee visited many communities, reached out to governmental and nongovernmental organizations nationwide, hosted a national flood risk summit, and carefully examined lessons learned in post-Katrina floods, including those resulting from Hurricane Sandy. It was clear to the committee that while some progress has been made, in general the flood challenge continues to receive scant attention and that much remains to be accomplished to safeguard the well-being of the people and property at risk. If the devastating impacts of Sandy and the losses sustained in

floods and hurricanes since Katrina were to be used as the measures of progress, the nation has failed to heed the call.

Consider that:

- There is no common vision of how the nation should organize and coordinate to reduce its flood risk. Proposals to deal with this challenge have languished in multiple congressional committees. The Unified National Program for Floodplain Management, called for by Congress, was last revised in 1994 and its recommendations lie dormant.

- We do not have a sound analysis of the potential risk to the nation from flooding. In 2007, Congress called for the president to conduct a national flood vulnerability assessment. Nonetheless, no funds have been provided by Congress to carry out that assessment, and we are operating in the dark as we continue to underfund our flood risk mapping programs. The public at large and many public officials clearly do not understand the risk we face.

- Much of our flood infrastructure—primarily dams and levees—remains in marginal or near-failing condition, and there is no realistic plan in place to deal with or improve these conditions. Federal funding is minimal, and local communities lack the resources with which to address the problem. Efforts to develop innovative funding mechanisms fall prey to political obstructionism.

- Climate change and population growth will further stress this already difficult situation. The Federal Emergency Management Agency reported earlier this year that as a result of this change and growth, the 100-year floodplain in the contiguous states could ex-

pand by 45 percent by the end of the 21st century. In addition, the continuing development affecting flood-prone areas exacerbates this problem. If something is not done to reduce risk, we are passing on to succeeding generations a potentially insurmountable challenge.

- Since Katrina struck, the nation has begun to shift from a mind-set of controlling floods to one of recognizing that absolute protection against these natural hazards is not possible. It is clear that when such action is justified and feasible our efforts must be focused on identifying our risks and developing and implementing a portfolio of approaches to deal with these risks—a portfolio referred to collectively as flood risk management. Despite the continuing tension between development and flood risk management, limited steps have been taken and progress has been made in some communities across the country to reduce and more effectively deal with flood risk. Awareness by the public has also increased, especially in light of recent catastrophic flooding events.

FLOOD RISK MANAGEMENT THE NEED FOR SOUND POLICIES AND PRACTICES

During the course of its investigations and meetings the TCFSP identified specific actions that should be implemented in the short term to reduce the nation's exposure and vulnerability to the consequences of floods and hurricanes. These actions have profound implications for communities nationwide that could benefit from flood risk management, and they underscore the importance of making the safety, health, and welfare of the American public a national priority.

Now is the time to accelerate progress and move aggressively forward to address the challenges of flood risk management. To do so the nation must:

- Develop a unified national (not federal) vision and supporting organizational framework for flood risk management;
- Define, apply, and evolve best practices in flood risk management;
- Identify and communicate flood risks to all affected parties;
- Provide adequate resources to support flood risk reduction strategies;
- Focus attention on the challenge of flood risk management and its evolution.

Ignoring the challenges is not an option. America is a compassionate nation that responds quickly to its citizens in times of crisis. How we act now is the difference between proactively minimizing the impacts of potentially life-changing events—for example, focusing on building resilience versus reactively recovering from catastrophic events—and failing to heed the lessons we should have learned. A failure to act today will have enormous future consequences. The call for action must once again be sounded.

FOLLOWING the tragedy of Hurricane Katrina in 2005 the U.S. Army Corps of Engineers asked ASCE to convene a panel of experts to provide an objective review of the findings of the Corps's Interagency Performance Evaluation Task Force (IPET). The IPET was established by the Corps to conduct a federal investigation into the failure of the New Orleans hurricane protection system during and following Hurricane Katrina. Following the review, the ASCE External Review Panel (ERP) prepared the report *The New Orleans Hurricane Protection System: What Went Wrong and Why*. This report identified 10 critical actions:

- 1) Keep safety at the forefront of public priorities.
- 2) Quantify the risks.
- 3) Communicate the risks to the public and decide how much risk is acceptable.

4) Rethink the whole system, including land use in New Orleans.

- 5) Correct the deficiencies.
- 6) Put someone in charge.
- 7) Improve the interagency coordination.
- 8) Upgrade engineering design procedures.
- 9) Bring in independent experts.
- 10) Place safety first.

Once five years had passed, ASCE found it appropriate to appoint a task committee to determine the status of the recommendations put forth in this report, not just with respect to New Orleans but to the United States as a whole. In January

2012 the ASCE Board of Direction authorized the TCFSP to examine the status of the recommendations, to determine whether progress has been made in implementing the calls to action, and to determine if the American public is now safer from the dangers of flooding. The committee's mission is as follows:

The mission of the Task Committee on Flood Safety Policies and Practices is to investigate whether the lessons learned from levee failures during Hurricane Katrina have been incorporated into the planning, design, construction, and management of engineering water resource projects and to provide a basis for influencing any needed change in public policy and engineering practice related to flood safety.

The committee includes, but is not made up exclusively of, members of the ERP, ASCE members involved in local flood policy, the chair of the IPET, and other flood safety experts. The committee met

six times over the course of a year and a half in Reston and Herndon, Virginia; Chicago; New Orleans; and San Francisco.

In April 2013 the committee hosted a summit entitled "Building a Framework for Flood Risk Management: Goals, Roles and Responsibilities, Resources, and Systems," which was held in Herndon, Virginia. Roughly 70 key local and federal government officials, leaders of nongovernmental organizations, practicing engineers, and other professionals interested in flood safety issues from across the country and abroad participated in the summit.

Summit participants focused on the creation of a shared framework for resilient flood risk management that requires a systems approach that targets the hazard and facilitates the consideration of all aspects of reducing risk and balancing resources and then communicates the risk to the stakeholders. Formulating a vision of future flood risk management requires clear and appropriate policies, as well as guidelines and standards that



Flooding on the bay side of Seaside, New Jersey, was extensive after Hurricane Sandy made landfall. The unprecedented storm surge prompted the National Oceanic and Atmospheric Administration to increase the number of storm surge forecasters at the National Hurricane Center beginning with the 2013 Atlantic hurricane season.

enable informed decision making. Participants also noted the importance of continuing to develop tools to understand and communicate the physical processes that predict performance of the physical flood risk infrastructure and span the spectrum of decision making, including social and environmental resources.

It was also noted that ASCE would like to have some involvement in the development of a national flood risk policy and that the committee would produce a document outlining the work of the committee and the findings of the summit. The report, to be published by ASCE later this year, is the basis of this article.

A clear message gleaned from the summit was the need for a common understanding of flood risk management—its major elements and objectives. The TCFSP believes that flood risk management seeks to reduce flood risk to communities and individuals through identification and analysis of the flood hazard, the vulnerability of communities to these hazards, and the potential resulting consequences. It also seeks to integrate and synchronize actions at various levels of government to mitigate risk.

The participants in the summit and the TCFSP envision that the federal government—in collaboration with state, tribal, and local governments, other concerned public and private organizations, and the public at large—will use forward-thinking flood risk management processes. These processes will reduce the vulnerability of the nation to dangers and damages that result from floods while concurrently protecting and enhancing the natural resources and functions of floodplains and supporting wise and sustainable economic development of appropriate coastal and riverine areas.

Flood risk management provides for:

- 1) Effective and sustainable management of risks posed by floods to life safety, human health, economic activity, cultural heritage, and the environment.
- 2) Collaborative risk sharing and risk management at all levels of government and by all stakeholders.
- 3) Risk-informed policies and funding prioritization.
- 4) The use of natural processes to mitigate the consequences of flooding.

Implementing flood risk management requires:

- 5) A common definition of flood risk and a consistent means of assessing risk.

- 6) Effective collaboration, clear communications, and well-defined roles, responsibilities, and authorities at all levels of government, the private sector, nongovernmental organizations, and the public. Those affected by floods must understand and have the tools to manage their personal, household, and neighborhood risks.

- 7) Balanced consideration of structural and nonstructural measures to foster a sustainable resilient infrastructure. This

balance includes using natural defenses to reduce risk while preserving, restoring, and enhancing ecosystems.

- 8) Basing land-use decisions on flood risk management principles that reflect community values, priorities, heritage, and equity.

- 9) Establishment of long-term, reliable funding mechanisms for flood risk reduction measures at the federal, state, and local levels.

- 10) Adapting flood risk management strategies to meet changing conditions.

Over the course of the summit many comments addressed the importance of defining what is meant by risk and how to measure it. Simply stated, risk is the potential for an unwanted outcome:

- The risk to life safety is the chance that people will lose their lives in flooding. This risk is measured by fatalities.

- The risk to human health is the chance that the physical, mental, or social well-being of affected people will be harmed by flooding. This risk is measured by injuries and metrics of mental and social health.

- The risk to economic activity is the chance that individuals or communities will lose property and structures and/or be subjected to a loss in the production, distribution,

and consumption of goods and services due to flooding. This risk is measured by such economic metrics as direct and indirect costs and unemployment.

- The risk to cultural heritage is the chance that a community will lose tangible or intangible attributes of their culture due to flooding.

- The risk to the environment is the chance that the quality of water, land, or air will be degraded by flooding. This risk is measured by such metrics of environmental quality as measurements of water quality, habitat loss, and ecosystem degradation.

Management of these risks involves balancing the level of

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the risk against the costs of decreasing the risk or the resources lost or damaged by accepting increases in the risk. Examples of decreasing risk mitigation measures can include structural means (levees, dunes, pump stations, resilient structures) and nonstructural means (evacuation planning, land-use decisions, creation of open space). There may also be benefits affecting this balance that are realized by increasing or decreasing the flood risk (for example, removing a dam may increase the flood risk but benefit the ecological system). Effective management of risk means that the desired level of risk is achieved for the intended costs and benefits of achieving it. Sustainable management of risk means that the means and methods used to manage risk will be effective for multiple generations into the future and will provide society, within its bounds, the capacity and opportunity to maintain and improve its quality of life indefinitely without degrading the quantity, quality, or availability of natural, economic, and social resources.

THE ROLES and responsibilities of some government entities and of private property, historic preservation, and environmental interests can be seen as in conflict and in competition with each other, which can impede effective flood risk management. In some cases reducing one stakeholder's risk can simply shift it to another location or stakeholder. Call to action 6 from the 2007 report of ASCE's ERP states simply, "Put someone in charge." This statement was based upon the finding that there was no system to resolve conflicting priorities between the numerous agencies that each had control of different parts of the hurricane protection system. It further stated that "until someone is put in charge of overall management and made accountable, organizational dysfunction will continue."

This recommendation has evolved into a declaration of shared risk across all levels of government. It is important to establish a strategy of collaborative management of the risks of flooding that focuses on optimal use of limited resources to achieve common goals. Without this assurance, cost-effective and sustainable strategies that require coordination between agencies are untenable.

A simple but important example is the role of state and local government agencies in emergency management. These agencies are responsible for ensuring that evacuation plans are in place, understood by the public, and initiated. To do this they rely on coordination of information from other agencies, for example, those responsible for weather reporting, tracking of flood elevation levels, and reservoir releases. Coordination is

crucial to ensure that the most appropriate decisions are made. Summit participants observed that many states have strengthened their oversight of emergency response planning and that the establishment of the Corps of Engineers' Silver Jackets Program—which brings together multiple agencies—has also strengthened the involvement of federal and state agencies in coordinating roles and responsibilities.

Another example concerns development in high flood risk areas. Existing development requires a delicate approach in balancing competing property interests with social and environmental values. For example, a strategy may be to incorporate resilience in new or established development within flood-prone areas. To implement this strategy requires the involvement of local governments that have jurisdiction over building codes. Such solutions as relocation or removal

of assets may be most effective but are often excluded from consideration due to perceived barriers between the federal and state agencies and the local government that has responsibility for land use. Another barrier to such measures is the anticipated loss of economic development, and as such a structural approach may be preferred. In some cases, this may transfer floodwaters (and risk) further downstream to another area or may increase the consequences in the event of an overwhelming flood or structural failure. The approach of purchasing areas of high flood risk has been successfully used as a proactive strategy in both urban and rural environments throughout the United States.

Collaborative risk sharing and risk management at all levels of government and by all stakeholders is required to promote effective flood risk management and to make sure that risk is reduced and not simply transferred to another region.

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HURRICANES KATRINA AND RITA in 2005, Hurricane Ike in 2008, the Midwest floods in 2011, and Hurricane Sandy in 2012 reminded the nation of the catastrophic effects of extreme weather events. The loss of more than 2,000 lives, the social disruption of hundreds of thousands of people, and the economic damages that have reached hundreds of billions of dollars could have been dramatically reduced through the implementation of effective flood risk management policies. Unfortunately, this nation's existing policies and funding choices will guarantee the continuation of these dramatic losses. As summit attendees confirmed, without giving the public a clear understanding of the risks that must be faced, it is difficult to achieve support for policies that will reduce these risks to people and property

from flooding and to take those actions following a disaster that will prevent their recurrence in the years ahead. Knowledge of the potential consequences of a major event and of the probability that such an event could occur effectively informs public decisions. Such risk-informed decisions help guide policies that limit new development in risk zones and support postdisaster rebuilding that takes into account the challenges to be faced in the future.

By successfully explaining the link between a hazard and its potential consequences, the medical profession has successfully persuaded the public and policy makers that an ounce of risk prevention is worth a pound of postdisaster cure. The United States has essentially eradicated polio and smallpox to the extent that protection against these diseases is no longer part of the immunization schedule for children. Engineers know how to reduce the risk of floods, whether caused by a natural event or failure of structures, but for a variety of reasons there has been limited success in gaining public support for their reduction. By identifying the flooding hazards that exist, the exposure and vulnerabilities that communities have to these hazards, and the potential consequences of hazard events, the nation is better able to develop policies that will prevent flood losses. Failure to develop risk information leads to complacency and unwise decisions.

Government expenditures and actions to reduce flood damage, whether in response to or in anticipation of an event, must be tied to risk. Where the identified risk is the greatest, the expenditures should be the largest. Dividing the funds equally among all who are at risk without regard to their level of risk is both fiscally and morally deficient. Incentives should exist to support effective flood risk management activities. Public officials should be held accountable for failures when governments do not consider risk or implement poor practices. Funding and support of postdisaster recovery should be prioritized based on the risks that must be faced in the actions that are being taken by the local communities to effectively deal with future flood conditions.

To effectively deal with flood damages, decision makers must understand the risks that must be faced and develop policies and actions that take these risks into account.

Far too often we as a society have chosen to alter natural processes and systems to assist in meeting a perceived need. A common example is developing floodplains for residential or industrial/commercial purposes. Through the lens of risk, this is a double negative. First, the loss of that natural resource for storing water during high-water periods will increase flooding elsewhere. Second, occupying that area with people and property dramatically increases the potential consequences from flooding. Both actions individually increase risk of losses; together they do so in a multiplicative way. A third negative that is too often overlooked is the multitude of other benefits that we receive from natural processes and systems—for example, clean air and clean water, biological diversity, and recreation. These benefits are often difficult to quantify using the traditional economic or life/safety metrics that are commonly used to characterize societal benefits, yet they are immensely important to our health and well-being.

We have also as a society chosen far too often to use a single approach—structural measures—to isolate developed flood-prone areas from the source of flooding. In most cases the design or performance limits of these structures are established through analyses that do not comprehensively consider risk and uncertainty in terms of the hazard, the reliability of the structures, or the consequences if these structures fail. Limits are set on the basis of such economic metrics as cost/benefit ratios or policies are established that focus more on affordability than on the mitigation of risk. As single point failure systems, they have no backup capability to reduce the extent of losses when their capacity is exceeded. This represents again a double-edged sword. We lose the benefits of the natural processes that were once in place, and when these structures fail, we suffer large losses.

The widespread adoption of this land-use practice has caused extensive losses in the past and huge (but uncalculated) vulnerabilities for the future, estimated as high as \$7 billion per year for the United States, according to the National Committee on Levee Safety. Gaining the benefits of the flood risk reduction capacity of natural processes and simultaneously reducing this vulnerability would dramatically reduce our flood risk exposure and contribute to a redirection of resources that are now applied to compensate for losses and recover from disasters. It is the difference between proactively investing to preserve or even remove areas from future losses once and deciding to pay multiple times over for losses and recovery.

We have to decide if we want to continue to use our resources for recovery or to use them to build a more robust economy and enhanced social well-being.

The elephant in the room is how to reverse many decades of past decisions that have created this situation. People currently occupying these areas are not anxious to relocate and would need significant compensation to facilitate their move to safer locations. Making insurance rates for occupation of these areas on the basis of risk is a tenet of the 2012 revision (Biggert-Waters Flood Insurance Reform Act) of the National Flood Insurance Program (NFIP) but has received great pushback because of the cost increases to current residents. This is a paradox that must be resolved in order to move forward.

While risk is a relatively simple concept—the product of the probability of an event and the resulting consequences—it is far from simple to apply given the dearth of relevant information and the variety of methods available for its estimate. In reality, there exists a broad spectrum of risk estimation options, some very general and even qualitative and others highly sophisticated.

In the wake of Katrina there have been a variety of risk assessments made for New Orleans and southeastern Louisiana. They ranged from the relatively sophisticated analyses for New Orleans conducted by the Corps of Engineers' IPET to the more regional assessment developed for the Louisiana Coastal Protection and Restoration Authority's program. In California a delta risk management strategy was developed to support risk mitigation decisions for the California Delta.

The methodologies and information bases applied varied considerably, and the uncertainty of the results, not

unexpectedly, was significant. With broad options available for estimating the probability of the hazard, the reliability of the flood risk reduction measures, and the potential consequences, the ultimate results can look quite different depending on the data methods chosen for each analysis.

An effective national risk assessment and risk management initiative will require a consistent definition of flood risk and an accepted framework for how risk should be estimated for different scales and purposes. It is also essential to understand the relationships of risk information generated from different methodologies. This would allow, for example, the meaningful comparison of regional data with those generated for a specific community or project. It is also necessary to enable the integration of risk information for adjacent regions and to gain a national perspective on risk and the potential for risk mitigation and reduction using available alternative measures.

Consistency is equally important in developing criteria for risk-based decision making. This can be viewed as developing standards for acceptable risk, guidance for incorporating uncertainty in risk decision criteria, and guidance for the frequency and detail required in conducting risk assessments. There are currently no agreed-upon standards or guidance for flood risk beyond those used for dam safety. The nation remains without a national levee safety program that could guide the assessment and application of risk information for the more than 100,000 miles of levees in this country.

Encouragement of effective and sustainable risk management requires that risks be measured and analyzed over time so that risk assessments can be updated and the management approaches can be adapted. Specific and publicly accepted metrics for risks to life safety, human health, economic activity, cultural heritage, and the environment need to be defined in such a way that they can be measured in a consistent, repeatable, and practical way. The metrics need to be measured frequently enough to capture their relationship to temporal factors that may affect them, including both natural and anthropogenic processes. Likewise, the approaches for managing risk must be continually revised on the basis of the updated risk assessments.

The various ways of assessing risk need to be consistent, practical, and transparent. National guidance for flood risk assessment is needed to provide a consistent approach. The tools for risk assessment should be such that they can be readily implemented by practicing engineers and understood by the public. Stakeholders should be included throughout the process for risk assessment so that the people making and affected by the risk management decisions are as informed as possible about the risks.

FOR EIGHT DECADES, the federal government has been seen as the driver of flood control and flood damage reduction for the nation, even though local governments have been on the front lines in dealing with floods. The roles of states, businesses, and nongovernmental organizations, as well as the public at large, have varied by location and interest. When overlaps or gaps exist in the delineation of roles and responsibilities, the viability of flood risk management strategies is brought into question, and such is the present condition in much of the United States. Over the years significant problems have arisen in the planning, design, construction, and operation and maintenance of flood risk management systems, both non-structural and structural. The current challenge, as typified in part by the thousands of miles of levees that have failed to meet standards, reflects the failure of those with interest in and responsibility for those levees to provide oversight and carry out required maintenance and upgrades as they become necessary.

It also reflects a failure to clearly delineate these responsibilities in intergovernmental and intragovernmental agreements and budgets. Although the 12-agency Federal Interagency Floodplain Management Task Force serves as a coordinating body at the federal level, coordination challenges remain, and little action is being taken to define federal/state relationships and responsibilities through any form of a unified national program.

The continued growth of development in flood-prone areas points out the divergence of focus between local governments that are responsible for land-use regulation and federal and state governments that guide emergency response and recovery for areas that should not

have been occupied. Local governments, by which the decisions on land use are being made, see the benefits of poor land-use decisions through increased developments and tax revenue. This is not sustainable. Such legislation as chapter 367 of California Assembly Bill 70 of 2007, which requires local communities to share in liabilities when a disaster occurs and the community has unreasonably approved new development, reflects an incentive-based approach. A governance structure that provides local governments with federal and state support and guidance in the execution of flood risk management strategies brings together problems and solutions.

Responsibility for risk communication is divided among all levels of government and within levels among many agencies. Messaging is not coordinated, and citizens become confused and often ignore the conflicting information. Risk communication aimed at raising public awareness is most effective when it is delivered at the local level by local leaders; however, this requires an understanding and a willingness to support this communication.

FAR TOO OFTEN we as a society have chosen to alter natural processes and systems to assist in meeting a perceived need. A common example is developing floodplains for residential or industrial/commercial purposes.

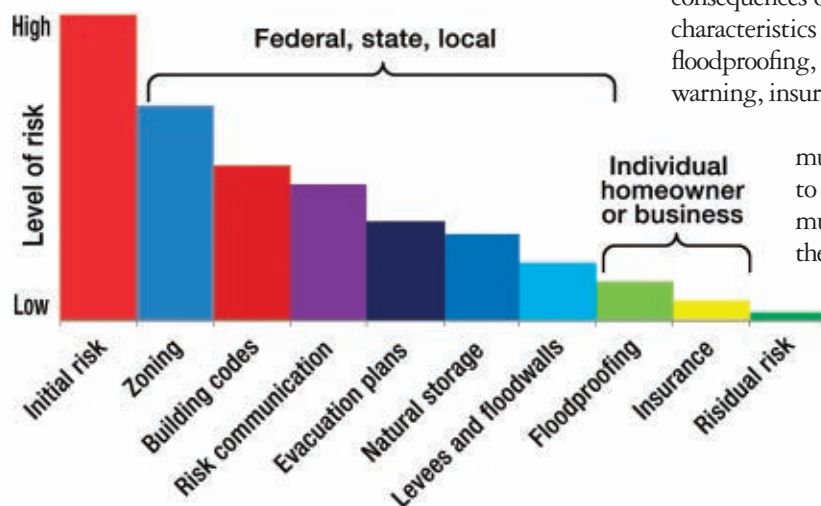
In communities that are prone to flooding, the options for mitigating flood risk may be challenging, but with collaborative federal, state, and local support of outreach, education, and funding, individuals and communities can take steps to reduce their risk. Building codes that help to mitigate loss of life and provide more resilient structures, for example, can be incorporated to reduce damages. Preplanned evacuation routes and drills can improve the response during an emergency and can reduce loss of life. Communities must not only understand their flood risk, they also must be aware of the options available to them to reduce these risks and have confidence that the actions they take will be effective in reducing that risk. Participation in the NFIP Community Rating System links the federal and local programs and will not only reduce risk and improve preparedness for communities but also can lower the flood insurance premiums paid by individual property owners.

Federal assistance for planning and funding mitigation and flood prevention measures is not widely understood by local governments. Simplified, regularly scheduled communication and organizational support from federal and state agencies will help individuals and local governments better understand

legislation forward. A clear need to bring together flood risk management leaders from all levels to address these roles and responsibilities still remains.

Flood risk management is founded on the understanding that flood protection is never absolute, that design levels of flood protection works may be exceeded, and that a residual risk of flooding will remain even with development of these works and measures. History has borne out these statements. Following Hurricane Katrina the nation's major flood agencies shifted from a focus on flood damage reduction to a focus on flood risk management and have encouraged the implementation of flood risk management strategies in communities around the nation. Such a strategy requires the use of all measures available—structural and nonstructural—to reduce, in a sustainable manner, the risk to those communities and populations exposed to potential flooding and to ensure their long-term resilience. The Corps of Engineers defines “structural measures” as those approaches that “alter the characteristics of the flood and reduce the probability of flooding in the location of interest.” Structural measures include dams, levees, and floodwalls. Nonstructural measures “alter the impact or consequences of flooding and have little to no impact on the characteristics of the flood” and include such approaches as floodproofing, elevation, land-use controls, evacuation, early warning, insurance, education, et cetera.

The figure below illustrates the use of these multiple measures in an effort to reduce the risk to the community through implementation of multiple means by all levels of government and the public. What is missing from this taxonomy is the inclusion of natural or nature-based infrastructure as a means to reduce flood risk. Included in this category are the uses of floodplains, floodways, and natural ecosystems for rerouting and storing floodwaters, the impact of natural marshes and wetlands on storm surge and waves, and the use of beaches and dune systems to reduce the impact of surge and waves.



Risk Reduction Measures. The red bar on the left represents the initial risk faced by a community. The bars to the right represent measures that can be taken to reduce the risk, each one making some contribution. The bar on the right represents the risk that remains after all measures are taken. Reduction to zero risk is not possible. (Source: National Research Council, *Levees and the NFIP, 2013 as modified from the USACE*)

and plan for flood disasters. One significant gap is an understanding of the lead time, cost sharing, and other prerequisites to obtain federal assistance. Federal and state flood prevention programs are generally tied to annual or biennial budget cycles and to lengthy agency approval cycles not commonly present at the local level.

Several studies have pointed out the need for national flood risk management legislation that would clearly define the roles of the federal government, state governments, and local governments, but little action has been taken to move such

While the use of all means of flood risk reduction seems logical, in execution there is a tendency, for both historical and psychological reasons, to place greater reliance on traditional structural measures even though in the long run nonstructural and nature-based measures tend to be more efficient and sustainable solutions. The use of natural systems for flood storage or floodwater diversion can also concurrently enhance the natural environment. The use of floodways and along-river wetland and lowland storage during the Mississippi River flood of 2011 proved the effectiveness of these works in reducing the damages from this near-record event.

Since the earliest days of flood control and flood protection, communities have relied on levees and dams to keep the floodwaters off of the property to be protected. In many cases these measures have succeeded over long periods, and their use in the protection of existing communities will continue to be a first line of defense. However, as recent experience around the globe has illustrated, such systems do fail, and when other

measures have not been put in place, the consequences may be disastrous. In addition, as new development is considered for flood-exposed areas, primary reliance on these structural measures may no longer be appropriate.

While strongly supported by reviews and studies conducted for the federal government and nongovernmental organizations, use of the full spectrum of available measures has been restrained by federal laws and regulations that have given greater weight to structural measures in calculating the benefits of a particular approach. Economic development was seen as the sole objective of such efforts. Federal project development guidance makes structural projects more feasible and requires less contribution by local governments for their execution than would be expected of nonstructural efforts. Simply looking at an economic balance sheet tilts decision making toward structural approaches.

In 2007, Congress established a new federal flood policy that gave equal attention to economic considerations, public safety, and environmental objectives and directed the president to revise the appropriate federal guidelines to comply with the new policy. In 2013, the U.S. Water Resources Council issued new principles that would permit greater attention to be given to nonstructural measures. However, through legislative instructions, Congress has prevented the Corps of Engineers from implementing these principles.

For far too long we have lacked a unified national strategy for managing flood-prone areas, which ironically represent key ecosystems that can dramatically reduce flood hazards as well as provide a multitude of other critical societal benefits. Land-use practices are in the hands of local authorities that too often have greatly increased flood risk while responsibilities for mitigating flood risk at the federal level emphasize recovery from losses. These practices have effectively privatized benefits and socialized losses. Until our national approach to this issue changes, the spiral of losses will continue.

Regaining the benefits of natural defenses is essential to the long-term viability of our communities that are located near water. Restoring ecosystems has broad benefits for society, reducing risk by reducing the hazard (likelihood of flooding) and reducing risk by limiting the people and assets exposed to flooding. Natural resource defenses used in concert with more traditional structural defenses will in many cases significantly reduce the level of performance needed from the traditional structures, reducing their cost and the extent of their impact on local activities. In addition, ecosystems can provide a significant source of resilience for structural measures by working in concert with them to provide enhanced capacity to deal with uncertainties and unexpected events.

We are at an inflection point with respect to flood risk. We can continue down our current path (spiral) that is generating an unaffordable increase in risk, or we can begin to exploit the full spectrum of available options, preferably as a system.

FLOODING DOES NOT RECOGNIZE geopolitical boundaries. Watersheds may extend across cities, counties, states, and international boundaries. Land-use decisions that address the potential risk of flooding require coordination

and planning within watersheds to be effective and to ensure that flood risks are not shifted from one community to another unfairly. These principles came out clearly in our interviews and during the summit discussions.

Flood risk impacts to property values can be a significant factor in how land uses are determined. Lower-income populations may live and work in areas with higher flood risks because of lower property values in those areas, which also limit options for relocation. Costs associated with flood insurance and more stringent building code requirements can also affect the valuation of property and the development options that are reasonable for flood-prone areas. There is a mix of existing development and potential development that may be affected. Rebuilding after a significant flood event may need to be evaluated differently from previously existing land uses.

A recognition of the complexities of land-use decisions related to flood risk management has become more important in many countries and across the United States. Clearly these challenges were of concern to the summit participants. Flood risk affects virtually all parts of the United States. Public recognition of risk associated with such naturally occurring events as flooding is challenging to achieve, even in the aftermath of flooding events in other parts of the country. The ability to effectively involve the public in planning efforts and in making decisions that can create more resilient land use and development in risk areas is an important responsibility of public agencies. Tools to support that communication and engagement with the public to address issues constructively are necessary as part of a national and local strategy. Questions of who is impacted and who pays are also part of the challenges to be addressed.

America's citizens want to believe that they will be supported during a natural disaster. Recognizing the need to mitigate the impacts of potential disasters as a civic responsibility is part of the message, as is the need for planning for postdisaster recovery. Many participants commented that postdisaster land-use plans need to be in place before the flooding occurs to provide a well-thought-out blueprint, not an emotional response. Land-use decisions are most often made at the local level. State and federal government may play a variety of roles in incentivizing or regulating those decisions. Funding can play a critical role in the ability to implement sustainable and resilient planning for land uses in flood risk areas. When low-income populations are most heavily affected, the target must be to achieve fairness and equity that are in balance with community values.

Effective flood risk management requires continuous and adequate funding of both structural and nonstructural approaches to reduce the growing flood risk to the nation. These activities are not being adequately funded at the federal, state, or local level, and the means to carry out this funding have not been identified or even appropriately examined. Over the course of the summit and during the committee visits it was clear that shrinking resources is a common challenge. As a result the national flood risk continues to increase and remains unaddressed. To illustrate:

• ASCE's 2013 *Report Card for America's Infrastructure* assigns a grade of D- to levees and a D to dams with estimated funding requirements to 2020 in excess of \$50 billion for each category. Current congressional action is considering a \$300-million annual program to deal with levee issues, an inadequate amount given the identified backlog.

• Funding for a flood vulnerability analysis for the nation, required by the Water Resources Development Act of 2007, has yet to be provided by Congress.

• The recently reauthorized NFIP is more than \$24 billion in debt, and efforts to bring the rates in line with the payouts have met strong opposition in Congress, ironically following its approval by the same body. The NFIP mapping program, essential to identification of baseline national flood exposure, is being funded at less than half of its needs.

With few exceptions, states have been unable to fund needed floodplain management programs within their jurisdictions and to effectively encourage development of balanced flood risk management strategies.

Resource support is a shared responsibility at all levels of government and includes private-sector investment. The questions of who benefits and who pays for infrastructure development and postdisaster recovery are still considered hot potatoes politically, and failure to address the question continues to limit progress in developing solutions. Private investment, public investment (floodproofing, insurance, et cetera), and federal, state, and local agency funding all play a role in dealing with flood risk management. Since resources are limited, it is critical to consider possible sources as well as mitigation strategies to reduce the need for resources.

Addressing deficiencies in aging infrastructure and ensuring that the infrastructure will be ready for the impacts of climate change and population growth will require significant resource commitments and close attention to innovative alternatives to structural approaches. The president, Congress, state and local governments, and businesses—including those that are directly affected by or operate water resources infrastructure—have been struggling to find funding outside of direct federal expenditures. Immediately following Hurricane Katrina, former Senator Warren Rudman and businessman Felix Rohatyn proposed the development of a National Infrastructure Investment Corporation with the authority to issue bonds to finance infrastructure projects. This proposal has not moved forward. The State of California has issued bonds to deal with critical infrastructure issues, but its example has not been followed elsewhere. Public-private partnerships have been suggested for some infrastructure, but unlike toll highways, which can provide a future revenue stream, such partnerships for levee maintenance and repair have lacked cred-

ibility. Where communities generate revenue to maintain infrastructure through assessments, these charges generally have not kept up with the full costs of providing these services. History indicates that it is frequently difficult for these agencies to garner the local political support necessary to raise the rates to a level necessary to carry out the needed infrastructure servicing. A large percentage of dams are privately or non-federally owned. There are a few state loan or grant funding sources to rehabilitate dams, but these funds usually support only state or municipally owned dams. Private owners, even the most conscientious ones, typically do not have the funding needed to perform necessary safety upgrades.

Because of the breadth of flood risk management activities and their oversight by different congressional committees, attention to needed resourcing lacks coherence, and unless the president and Congress, working with the states, are able to put together a realistic and sustainable program, the backlog of activity in flood risk management will continue to increase, as will the national flood risk.

EFFECTIVE flood risk management requires continuous and adequate funding of both structural and nonstructural approaches to reduce the growing flood risk to the nation.

IT IS GENERALLY EXPECTED that sea level rise will increase the frequency of flooding in coastal communities, with resultant economic and social disruption. While waters from storm events recede, sea level does not, and in some cases entire shoreline features that have previously provided some natural protection may be

washed away in a single storm. Because today's king tide could well be the future's mean sea level, we will need to adapt our communities and our built environment to the anticipated change. Climate change poses additional threats of flooding by increasing the frequency, severity, and duration of flood events. With every storm event, maps that had once depicted areas as being free of flooding may now show that communities and infrastructure are prone to flooding. Population increases through this century will drive much development to potentially hazardous areas.

In the face of change and given the limited financial resources available, protecting flood-prone communities will become increasingly difficult and the need for more effective land-use planning all the more important. Communities will have to become more resilient. Strategies to address the frequency and consequences of flooding must rely on portfolios of risk reduction methods instead of on a single measure. Flood maps must be regularly updated to communicate the most accurate information available. Plans to develop low-lying areas or to rebuild them after a flood event should be based on a full understanding of the long-term costs of recovery and those that will be incurred in adapting over time. This can be accomplished under some circumstances by elevating the structures to account for rising sea levels and hydrologic un-

certainty and by making full use of a wide range of mitigation measures, including dry and wet floodproofing, citizen education, early warning systems, improved building codes, and risk transfer through insurance. In some cases, strategic retreat may ultimately be preferred over hard infrastructure or non-structural solutions.

DURING THE COURSE of the committee investigations, the summit, and the committee meetings, a number of actions were identified that should be implemented in the short term to reduce the nation's exposure and vulnerability to the consequences of floods and hurricanes. The committee recommends that:

1) The president and Congress jointly develop a coherent and sustainable funding strategy to address the growing need for infrastructure maintenance and renewal and for related nonstructural flood risk management activities at the federal, state, and local levels.

a) The strategy should include innovative methods for shared federal/state/local funding of infrastructure projects and public-private partnerships where appropriate.

Possible approaches could include:

i) A national infrastructure bank that would have the ability to leverage private and public capital to support flood risk reduction infrastructure projects of a national and regional significance.

ii) The establishment of funding mechanisms similar to America Fast Forward bonds to support municipal flood risk management activities. The program would permit low-cost infrastructure financing for municipalities and their private-sector partners by providing interest subsidies on taxable bonds.

iii) The authorization of a pilot, flood-focused version of the Water Infrastructure Finance and Innovation Act that would support flood risk mitigation projects whose cost is greater than \$20 million and that would be too large to be considered under provisions of the proposed 2014 Water Resources Development Act.

b) ASCE should establish a committee to work with the president and Congress in developing the funding strategy. The committee should work toward identifying means of "full funding" of approved water projects, starting at the federal level and then migrating toward shared funding packages for federal, state, and local entities.

2) The Federal Interagency Floodplain Management Task Force, in collaboration with the states, should prepare and promulgate a 21st-century unified national program for floodplain management to provide a vision and path forward for a risk-and-resilience-based approach to mitigating national flood challenges.

3) Congress should provide funding to conduct the national flood vulnerability study it stipulated in the 2007 Water Resources Development Act and has failed to fund. Such an action will ensure that the governments and the public are aware of their existing flood risks.

4) Working collaboratively, the Corps of Engineers, the Fed-

eral Emergency Management Agency, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and the Natural Resources Conservation Service should support the development of specific pilot projects that demonstrate the long-term benefits of approaching flood risk management and mitigation through an application of the principles of resilience, natural systems utilization, and integrated watershed management.

5) Federal, state, and local governments should support initiatives to develop flood risk management strategies that provide for a balanced use of structural and nonstructural flood risk mitigation measures and that lead to long-term sustainable approaches to dealing with the growing national flood risk.

6) In planning flood risk mitigation activities, federal, state, and local governments should take into consideration both the short- and long-term impacts of climate change, sea level rise, population growth, and infrastructure renewal. These planning conditions should be periodically reviewed to ensure their currency in the face of rapid change.

7) The Council on Environmental Quality should accelerate the development of guidelines to support implementation of the newly promulgated federal principles and requirements that provide a basis for including public safety and ecosystem values in decision making for water resources investments. The guidelines are needed to define how such inclusion should be accomplished and to provide incentives for moving in that direction. It is especially important to create a framework that relates natural systems benefits to other type of benefits to allow holistic assessments.

8) The Federal Emergency Management Agency, in collaboration with the National Oceanic and Atmospheric Administration, the Corps of Engineers, and the U.S. Geological Survey, should support the development of a coalition of social, professional, and environmental nongovernmental organizations (ASCE included) to carry out a coordinated communication campaign to educate the public concerning its exposure to flood risks and the actions that need to be taken to deal with these risks.

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