# Grand Challenges *for* Disaster Reduction

## National Science and Technology Council
Committee on Environment and Natural Resources

A Report of the
Subcommittee on Disaster Reduction

June 2005

sdr
subcommittee on disaster reduction

EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

EXECUTIVE OFFICE OF THE PRESIDENT
**OFFICE OF SCIENCE AND TECHNOLOGY POLICY**
WASHINGTON, D.C. 20502

June 2005

Dear Colleague:

Every year, natural and technological hazards in the United States cost an estimated $1 billion per week in the form of lives lost and public and private properties destroyed. In 2004 alone, more than 60 major disasters, including floods, hurricanes, earthquakes, tornadoes, and wildfires, struck the United States. Reducing these losses requires collaboration at all levels and a coordinated, interagency approach. The Subcommittee on Disaster Reduction (SDR), an element of the President's National Science and Technology Council (NSTC), represents the expertise of more than 20 Federal agencies with disaster reduction missions and facilitates our national strategies for effective use of science and technology to reduce disasters.

To develop a ten-year strategy for disaster reduction through science and technology, the members of the SDR collaborated with scientists and engineers worldwide to identify a suite of Grand Challenges for disaster reduction. This document presents six Grand Challenges for disaster reduction and provides a framework for prioritizing the related Federal investments in science and technology. Addressing these Grand Challenges will improve America's capacity to prevent and recover from disasters, thus fulfilling our Nation's commitment to reducing the impacts of hazards and enhancing the safety and economic well-being of every individual and community.

Sincerely,

John H. Marburger, III
Director, Office of Science and Technology Policy
Science Advisor to the President

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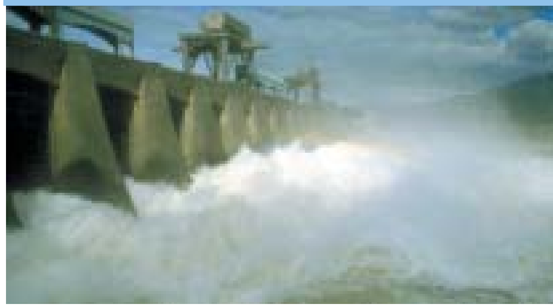
# Contents



# Executive Summary

Despite significant progress in the application of science and technology to disaster* reduction, communities are still challenged by disaster preparation, response, and recovery. We have reduced the number of lives lost each year to natural disasters, but the costs of major disasters continue to rise. A primary focus on response and recovery is an impractical and inefficient strategy for dealing with these ongoing threats. Instead, communities must break the cycle of destruction and recovery by enhancing their disaster resilience.

The Subcommittee on Disaster Reduction identified four key characteristics of disaster-resilient communities:

- Relevant hazards are recognized and understood.
- Communities at risk know when a hazard event is imminent.
- Individuals at risk are safe from hazards in their homes and places of work.
- Disaster-resilient communities experience minimum disruption to life and economy after a hazard event has passed.

High-priority science and technology investments, coupled with sound decision-making at all levels, will dramatically enhance community resilience and thus reduce vulnerability. In support of this goal, the following six Grand Challenges provide a framework for sustained Federal investment in science and technology related to disaster reduction:

**Grand Challenge #1—Provide hazard and disaster information where and when it is needed.** To identify and anticipate the hazards that threaten communities, a mechanism for real-time data collection and interpretation must be readily available to and usable by scientists, emergency managers, first responders, citizens, and policy makers. Developing and improving observation tools is essential to provide pertinent, comprehensive, and timely information for planning and response.

**Grand Challenge #2—Understand the natural processes that produce hazards.** To improve forecasting and predictions, scientists and engineers must continue to pursue basic research on the natural processes that produce hazards and understand how and when natural processes become hazardous. New data must be collected and incorporated into advanced and validated models that support an improved understanding of underlying natural system processes and enhance assessment of the impacts.

**Grand Challenge #3—Develop hazard mitigation strategies and technologies.** To prevent or reduce damage from natural hazards, scientists must invent—and communities must implement—affordable and effective hazard mitigation strategies, including land-use planning and zoning laws that recognize the risks of natural hazards. In addition, technologies such as disaster-resilient design and materials and smart structures that respond to changing conditions must be used for development in hazardous areas.

* Note: In this document, the terms disasters and hazards encompass events with both natural and technological origins.

By designing and building structures and infrastructures that are inherently hazard resilient, communities can greatly reduce their vulnerability.

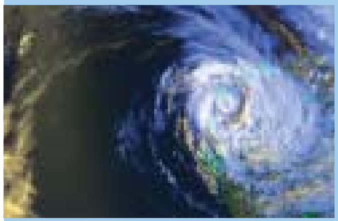
**Grand Challenge #4—Recognize and reduce vulnerability of interdependent critical infrastructure.** Protecting critical infrastructure systems, or lifelines, is essential to developing disaster-resilient communities. To be successful, scientists and communities must identify and address the interdependencies of these lifelines at a systems level (e.g., communications, electricity, financial, gas, sewage, transportation, and water). Using integrated models of interdependent systems, additional vulnerabilities can be identified and then addressed. Protecting critical infrastructure provides a solid foundation from which the community can respond to hazards rapidly and effectively.

**Grand Challenge #5—Assess disaster resilience using standard methods.** Federal agencies must work with universities, local governments, and the private sector to identify effective standards and metrics for assessing disaster resilience. With consistent factors and regularly updated metrics, communities will be able to maintain report cards that accurately assess the community's level of disaster resilience. This, in turn, will support comparability among communities and provide a context for action to further reduce vulnerability. Validated models, standards, and metrics are needed for estimating cumulative losses, projecting the impact of changes in technology and policies, and monitoring the overall estimated economic loss avoidance of planned actions.

**Grand Challenge #6—Promote risk-wise behavior.** Develop and apply principles of economics and human behavior to enhance communications, trust, and understanding within the community to promote "risk-wise" behavior. To be effective, hazard information (e.g., forecasts and warnings) must be communicated to a population that understands and trusts the messages. The at-risk population must then respond appropriately to the information. Significant progress is being made, but this is an ongoing challenge that can only be met by effectively leveraging the findings from social science research.

Advances in science and technology alone cannot fully protect the Nation from all hazards. In support of these Grand Challenges, key research and major technology investments must be linked to effective "risk-wise" policy decisions at all levels. Change must occur at both the policy level and in the societal perception of risk so that adoption and adaptation keep pace with advances in science and technology. A sustained emphasis on risk mitigation and public/private partnerships is essential throughout all aspects and at all levels of the community. Within this integrated planning context, improved coordination of sustained Federal science and technology investment to address the Grand Challenges for Disaster Reduction will enhance disaster resilience and national safety.

## Disaster Profile: Hurricane



Since 1900, hurricanes and tropical storms making landfall on the U.S. Gulf Coast have caused more than 9,000 deaths and more than $100 billion in damages (adjusted to 2004 dollars) to homes and property.[1] In 2003, a single storm, Hurricane Isabel, caused over $4 billion in damages on the Atlantic Coast and resulted in the loss of 47 lives.[2] In 2004, a series of major storms struck the Atlantic and Gulf Coasts of the United States, affecting 15 states and costing billions of dollars in damages.

To protect against this hazard, atmospheric conditions must be continually monitored to detect the storm in the early stages and apply models to predict its motion and intensity. Once the storm is detected, everyone must be informed quickly and provided with understandable, actionable information, such as evacuation plans and shelter locations. Individuals must be aware of the risk and know how to act. Before the storm, knowledge of local weather patterns and micrometeorological effects will be applied. This knowledge should be incorporated into building codes and the choice of building materials, as well as community design, to mitigate against property damages and disruption to essential utilities and services.



# Introduction: What's at Stake?

Each year, natural and technological disasters cause an estimated $52 billion in damages in the United States in terms of lives lost, disruption of commerce, properties destroyed, and the costs of mobilizing emergency response personnel and equipment.[3] As the costs continue to rise, we must move from response and recovery to proactively identifying hazards that pose threats and taking action to reduce the potential impacts.

To reduce future escalation of these costs, the United States invests significant Federal funds in disaster-related science and technology to reduce the loss of life and property damage from hazards. Despite this progress, however, the United States still faces enormous losses each year from hazards.

Hazards will always exist. Whether they become disasters depends upon our disaster resilience—our capacity to prepare, mitigate, respond, and recover. This report outlines key opportunities for scientific and technological advances that will enhance disaster resilience and thus improve the Nation's ability to face disasters.

## Hazards in the United States

**Drought.** Drought is a complex and widespread natural hazard, affecting more people in the United States than any other natural hazard and accumulating average annual estimated losses between $6 and $8 billion. The magnitude and complexity of drought hazards have increased in association with growing population, population shifts to drier climates, urbanization, and changes in land and water use.[4]

**Earthquakes.** Each year, the United States experiences thousands of earthquakes and, on average, seven earthquakes per year have a magnitude of 6.0 or greater, enough to cause serious damage.[5] Although major advances have been achieved in understanding and mitigating earthquake hazards, 75 million Americans in 39 states face significant risk from earthquakes.[6]

**Floods.** Floods are the most frequent natural disaster; one in three Federal disaster declarations is related to flooding.[7] An increase in population and development in flood-prone areas, along with an increase in heavy rain events during the past fifty years, have gradually increased flood-related economic losses.[8] Property damages from flooding average $2 billion a year.[9]

**Public Health/Environmental Disaster.** Public health and environmental disasters may arise from natural events or human-caused releases of hazardous materials. The hazard may be primary or it may be the result of a previously-existing hazard. Disease outbreaks, such as Severe Acute Respiratory Syndrome (SARS), clearly show the importance of public health monitoring, emergency communication, and international cooperation.

*Mount Saint Helens, November 4, 2004,*
*USGS photograph taken by Jim Valance and Matt Logan*

Diseases spread by common vectors, such as West Nile Virus, reinforce the need for a public health education program in every community.

**Severe Weather.** Due to changes in population demographics and more complex weather-sensitive infrastructure, Americans today are more vulnerable than ever before to severe weather events caused by tornadoes, hurricanes, severe storms, heat waves, and winter weather. For example, during May 2003, the United States was hit with 543 tornadoes, breaking the previously existing monthly record of 399 tornadoes established in 1992.[10] In many cases, communities underestimate the dangers of extreme weather events, as was the case in 1995, when a heat wave in Chicago killed 739 people.[11] Over the past 30 years coastal population growth has quadrupled; more than 69 million people now reside along hurricane prone coastlines in the United States.[12]

**Technological.** Technological hazards involve the release of hazardous substances—chemicals, toxic substances, gasoline and oil, nuclear and radiological material, flammable and explosive materials, in the form of gases, liquids, or solids—that impact human health and safety, the environment, and/or the local economy. Such hazards exist during production, storage, transportation, use and disposal and can adversely impact oceans, groundwater systems, streams, rivers, agricultural fields, and even urban areas.

**Volcano.** The United States is among the most volcanically active nations in the world with nearly 70 active or potentially active volcanoes.[13] During the 20th century, volcanic eruptions in Washington, Oregon, California, Alaska, and Hawaii devastated thousands of square miles and caused substantial economic and societal disruptions and loss of life. Even with improved abilities to identify hazardous areas and predict eruptions, increasing numbers of people face volcanic hazards as a potential danger.[14]

**Wildland Fire.** Despite national progress in reducing wildland fire hazards, tens of millions of acres of American wildlands and thousands of communities at the wildland/urban interface still are at risk of catastrophic wildland fire. During the winter rainy season, disastrous debris flows often follow. The extreme fire season of 2000 saw the largest areas burned by wildland fires in the United States since the 1960s. From 1999 to 2002, the average area burned by wildland fire was 6.1 million acres (24,685.82 kilometers2), with an estimated cost of $1.1 billion for wildland fire suppression.[15]

# Grand Challenges: A Framework for Action

In partnership with local, state, Federal, and international experts, the members of the the Subcommittee on Disaster Reduction identified four key characteristics for disaster-resilient communities:

- Relevant hazards are recognized and understood.
- Communities at risk know when a hazard event is imminent.
- Individuals at risk are safe from hazards in their homes and places of work.
- Disaster-resilient communities experience minimum disruption to life and economy after a hazard event has passed.

If addressed, the critical problems in science and technology outlined here can help achieve these characteristics in every community. These Grand Challenges require sustained Federal investment in research, education, communication and the effective application of technology. They represent an ongoing effort by scientists and engineers to improve disaster resilience and demand focused Federal attention.

## Disaster Profile: Earthquake

Following the 1994 Northridge Earthquake, the U.S. Geological Survey created a Working Group (WG99) to reassess the likelihood of a large-scale earthquake affecting the San Francisco Bay area in the coming years. The WG99 determined that there is a 70% (+/- 10%) chance the region will experience a magnitude 6.7 or greater earthquake and an 80% chance of a magnitude 6.0 to 6.6 earthquake occurring before the year 2030.[16] The economic damage and potential deaths resulting from a large magnitude earthquake are considerable. Specifically, damages from a single large metropolitan earthquake could result in up to $100 billion dollars in direct losses.[17]

Reducing our risk of loss from earthquakes requires quantitative, predictive models of earthquake occurrence, processes, and effects. These models improve prediction capabilities and support early warning. At the same time, appropriate building codes and structural retrofitting are needed to protect against collapse during and after the quake and to prevent secondary or cascading hazards.

# Grand Challenge 1

## Provide Hazard and Disaster Information Where and When It Is Needed.

To identify and anticipate the hazards that threaten communities, a mechanism for real-time data collection and interpretation must be readily available to and usable by scientists, emergency managers, first responders, citizens, and policy makers. Developing and improving observation tools is essential to provide pertinent, comprehensive, and timely information for planning and response.

## Challenges:

**Improve data collection to increase understanding of the ways in which hazards evolve.** Improve data collection through networks of sensors that enhance fundamental understanding of the nature and threats of hazard conditions. Sensors must become not only more accurate and reliable, but more specific. Improved Earth observations, remote sensing, and real-time containment detecting technologies are needed to provide comprehensive real-time data on hazardous conditions, aid hazard forecasting and allow researchers to recognize warning signs.

**Create standards for sharing, storing and analyzing data.** Standards for storing and sharing hazard-related data must be established so that information can be rapidly transferred and shared among agencies and made reliable for researchers and response managers. Universal tools should exist to facilitate the integrated analysis and distribution of hazard-related data across all Federal, state and local databases.

To meet this Grand Challenge, the following key research requirements and major technology investments also must be addressed:

**Key research requirements:** Develop improved sensing capabilities and deploy expanded, modern, and integrated data collection systems that provide real-time data for use in modeling of hazardous conditions, consequence forecasting, and warnings. ■ Develop protocols for searchable, all-hazards Internet-accessible data systems. ■ Develop next generation network architectures for real-time data sharing from distributed sensors.

**Major technology investments:** Deploy an integrated, reliable information infrastructure that provides real-time access to data and models for hazard analysis, consequence forecasting, and rapid detection of negative outcomes. ■ Develop universally adopted standards for data sharing to speed transfer of information. ■ Incorporate geographical location data (using Geographic Information Systems (GIS) and Global Positioning Systems (GPS)) into systems that provide real-time, high quality, integrated social and environmental information for emergency response purposes.

### Disaster Profile: Tsunami

Tsunamis are low probability disasters with very large impacts, as was demonstrated by the Indian Ocean tsunami. On December 26, 2004, a magnitude 9.0 earthquake occurred off the coast of Sumatra 18.6 miles (30 kilometers) below sea level. The earthquake and underwater landslides produced waves over 100 feet (30.48 meters) high along the Sumatra coastline which then traversed the Indian Ocean within 10 hours, reaching speeds of 500 miles (804.67 kilometers) per hour. Like the Indian Ocean tsunami, approximately 90% of tsunamis worldwide are caused by earthquakes, but volcanoes, landslides, and meteorites also can cause tsunamis. Tsunamis have occurred in the U.S. along the coasts of the Pacific Northwest, Hawaii, Alaska, and Caribbean and Pacific territories; volcano-induced local tsunamis are a particular risk for Hawaii and the Northern Marianas islands.

Networks of sensors must be in place to detect tsunamis at sea, but it also is important to identify high-risk coastal communities and target those communities for hazard mitigation plans and projects. The technical systems for detecting and monitoring earthquakes and tsunamis must be complemented by national and local warning systems, trained local officials, and an educated and appropriate citizen response.

# Grand Challenge 2

## Understand the Natural Processes That Produce Hazards.

To improve forecasting and predictions, scientists and engineers must continue to pursue basic research on the natural processes that produce hazards and understand how and when natural processes become hazardous. New data must be collected and incorporated into advanced and validated models that support an improved understanding of underlying natural system processes and enhance assessment of the impacts.

### Challenge:

**Improve models and visualization techniques.** Improved models and visualization techniques must exist to make data more usable for researchers and to aid forecasting. Modeling should be applied to all areas of study, including meteorological, geological, resource management, and social science applications. Advanced modeling techniques should be used to demonstrate the dynamic nature of evolving hazards, indicate potential adverse human and ecologic exposures, aid hazard prediction and assessment, and serve as roadmaps for dealing with future events.

To meet this Grand Challenge, the following key research requirements and major technology investments also must be addressed:

**Key research requirements:** Continue and improve data collection and observations of hazard-related processes. ■ Develop and improve forecasting models and visualization techniques to provide timely and accurate information on the occurrence of hazardous events, consequences, and immediate steps that should be taken to reduce impacts. ■ Improve methods for validating these models. ■ Create and accelerate improvements in models of physical, chemical, and biological processes to enable a greater understanding of hazard interdependencies, predictive patterns, impacts, and cumulative effects on life, property, and the environment.

**Major technology investments:** Expand and improve the network that provides access to computational and simulation resources necessary for analysis and prediction.

## Disaster Profile: Severe Ice Storm / Freezing

The property damage and loss of life due to ice storms and freezing can be catastrophic in terms of a disruption in services and damages caused to local business, crops and agriculture. The most severe impacts of such storms is loss of power, and extensive physical damages to structures. Additionally, states in which agriculture plays a large role in overall economic health suffer economy losses if freezing temperatures last more than a few weeks.

To reduce the impact of ice storms, continuous and useful information about the hazard must be made available to everyone affected. Geographic information systems can be used to provide integrated weather information and road conditions. Identifying the effects of wind on ice-laden structures and trees, of low visibilities in blowing snow, and the impact on just-in-time transportation systems can inform mitigation efforts and reduce disruption.


*2004 Hurricane Season, The University of Wisconsin-Madison, Space Science and Engineering Center, November 30, 2004*

# Grand Challenge 3

## Develop Hazard Mitigation Strategies and Technologies.

To prevent or reduce damage from natural hazards, scientists must invent—and communities must implement—affordable and effective hazard mitigation strategies, including land-use planning and zoning laws that recognize the risks of natural hazards. In addition, technologies such as disaster-resilient design and materials and smart structures that respond to changing conditions must be used for development in hazardous areas. By designing and building structures and infrastructures that are inherently hazard resilient, communities can greatly reduce their vulnerability.

## Challenges:

**Create resilient structures and infrastructure systems using advanced building technologies.** Develop more advanced construction materials and technologies that create resourceful, intelligent, and self-healing structures. Structural systems must continue to be designed with disaster resilience in mind, and new materials and technologies must be available to create facilities that remain robust in the face of all potential hazards. "Smart" building technologies, which allow for self-diagnosis of damage and structural stability, should be employed.

**Support structural advances with effective non-structural mitigation.** All advances in building technology must be supported by appropriate nonstructural mitigation measures including land use and zoning regulations based on climatological and geological data. Community planning decisions should be designed to minimize damage and aid recovery.

**Quantify the monetary benefits of disaster mitigation using economic modeling.** Economic modeling is necessary to support investment decisions and demonstrate that substantial savings can be achieved by instituting disaster mitigation policies on a local and national level prior to investment in mitigation projects. Reliable data must be acquired to ground economic models empirically, and intangible and indirect impacts should be included in the model.

To meet this Grand Challenge, the following key research requirements and major technology investments also must be addressed:

**Key research requirements:** Encourage investment in developing, modeling and monitoring impacts of cost-effective and beneficial mitigation technologies. ■ Continue development of smart structural systems that detect and respond to changes in structure and infrastructure condition, and that predict failure. ■ Continue development of new materials and cost-effective technologies to retrofit existing inventory of buildings, bridges, and other lifeline structures. ■ Create integrated all-hazard methodologies for engineered systems.

### Disaster Profile: Severe Flooding

According to the NOAA National Weather Service, floods were the number-one natural disaster in the U.S. during the 20th century in terms of lives lost and property damage.[18] In 1993 alone, flooding in the Mississippi Basin resulted in an estimated $12 to $16 billion in damages.[19]

To prepare for floods, advanced modeling techniques must be employed to project real-time flood hazard impacts for large and small basins while integrated, area-targeted, multi-media systems issue warnings on flash-floods and other rapid on-set disasters. The cumulative impacts on the hydrology and hydraulics of flooding and drought must be incorporated into land use measures. Finally, immediate analysis must be provided following the flood to facilitate recovery operations and restoration or removal of affected facilities.

# Grand Challenge 4

## Recognize and Reduce Vulnerability of Interdependent Critical Infrastructure.

Protecting critical infrastructure systems, or lifelines, is essential to developing disaster-resilient communities. To be successful, scientists and communities must identify and address the interdependencies of these lifelines at a systems level (e.g., communications, electricity, financial, gas, sewage, transportation, and water). Using integrated models of interdependent systems, additional vulnerabilities can be identified and then addressed. Protecting critical infrastructure provides a solid foundation from which the community can respond to hazards rapidly and effectively.

## Challenges:

**Develop science and technology to prevent cascading failures in public infrastructure systems.** Develop tools and models to provide a more robust understanding of infrastructure interdependencies in order to protect the public infrastructure, to allow continuity of services, and to prevent cascading failures. Robust infrastructure systems should guard against damage from natural and technological hazards and feature redundant, rapidly resolving systems that allow any failures to be isolated and repaired with no disruption to other components. Additionally, infrastructures must be designed to protect people from secondary or cascading hazards. Risk assessment tools should be used to determine the impacts of planned development so appropriate measures can be taken to mitigate threats to infrastructure.

**Enhance the ability to protect public health before and after a hazard event.** Increased understanding of hazard events and their impact on public health can help protect the public before and after a hazard event. Communities should be designed to maintain sanitary conditions and prevent contamination to water supplies during and after hazard events. Scientific knowledge of potential threats to public health should be used in the creation of emergency response plans. Delivery of emergency services must be uninterrupted by the hazard. Public health conditions must be rapidly and effectively addressed to minimize the impact on people, animals, and the environment.

### Disaster Profile: Wildland Fire

Wildland fires commonly occur naturally and may significantly contribute to forest health and wildlife habitat. However, a large buildup of underbrush and small trees coupled with the prolonged drought such as the one currently affecting the Western U.S. has increased the potential for large, catastrophic wildland fires in the Southwest and Western states. The 2003 California wildland fires caused more than 743,000 acres (3006.81 kilometers$^2$) of brush and timber to be burned, 3,300 destroyed homes, 26 deaths.[20]

As with any threat, knowledge of the hazard is essential to reducing the danger. Enhanced knowledge of fuel sources and wildland fire behavior must continue to be incorporated into predictive models. Outreach programs must continue to be designed to more fully inform the public of the impacts of weather, insect and disease infestation, human actions, and other factors on wildland fires. Reducing unnaturally dense vegetation and the adoption of fire-safe practices such as safe fuel storage by all communities can mitigate against the spread of wildland fires, but additional steps also must be taken to reduce the spread of secondary hazards resulting from wildland fires (e.g., flooding and debris flows).

To meet this Grand Challenge, the following key research requirements and major technology investments also must be addressed:

**Key research requirement:** Develop improved assessment methods for analyzing the vulnerability and interdependence of infrastructure systems. ■ Develop innovative assessment models for emergency response procedures including addressing all threats to public health rapidly and effectively.

**Major technology investment:** Develop information acquisition systems that can be used to validate evaluations of resilience and response. ■ Identify and deploy cost-effective technologies that ensure survivability of critical utilities and other infrastructures.

# Grand Challenge 5

## Assess Disaster Resilience Using Standard Methods.

Federal agencies must work with universities, local governments, and the private sector to identify effective standards and metrics for assessing disaster resilience. With consistent factors and regularly updated metrics, communities will be able to maintain report cards that accurately assess the community's level of disaster resilience. This, in turn, will support comparability among communities and provide a context for action to further reduce vulnerability. Validated models, standards, and metrics are needed for estimating cumulative losses, projecting the impact of changes in technology and policies, and monitoring the overall estimated economic loss avoidance of planned actions.

## Challenges:

**Support intelligent community planning and investment strategies and protect natural resources with comprehensive risk assessments.** Risk assessments should be conducted to determine the likelihood and potential damages of hazard events and to identify at-risk communities or locations. Completed assessments can be used to guide investment and land-use decisions to protect the community and the natural environment. An integrated understanding of hazards requires understanding human behaviors that enhance or diminish the likelihood that potentially hazardous conditions will produce disastrous events.

**Assess the resilience of the natural and human environment.** Comprehensive assessments must include examination of the impact of natural and technological hazards on both the constructed and natural environment. Further, community planning must include steps based on scientific research to prevent loss of natural resources during a hazard event.

**Learn from each hazard event.** All hazard events should be analyzed and the results made public to support ongoing hazard research and future mitigation plans. Predisaster planning should be put into effect immediately following any hazard and should be the driving force behind all response and recovery actions for future events.

To meet this Grand Challenge, the following key research requirements and major technology investments also must be addressed:

**Key research requirements:** Establish methods and standards for evaluation of resilience to hazards to include economic, ecological, and technological consequences of disasters. Base risk assessments on this data. ■ Use standard methods to gauge improvement in resilience following investments in planning and mitigation. This research must include contributions from all disciplines that play a role in understanding hazards and mitigation, including the social sciences.

**Major technology investments:** Complete risk assessments for Federal facilities, critical facilities, and at-risk communities. ■ Develop comprehensive pre-event recovery plans.

# Grand Challenge 6

## Promote Risk-Wise Behavior.

Develop and apply principles of economics and human behavior to enhance communications, trust, and understanding within the community to promote "risk-wise" behavior. To be effective, hazard information (e.g., forecasts and warnings) must be communicated to a population that understands and trusts the messages. The at-risk population must then respond appropriately to the information. Significant progress is being made, but this is an ongoing challenge that can only be met by effectively leveraging the findings from social science research.

## Challenges:

**Raise public awareness of local hazards.** Reliable and integrated all-hazard data must be available to citizens and local decision makers to drive appropriate planning, mitigation, response, and recovery decisions.

**Warn people with consistent, accessible, and actionable messages and a national all-hazards emergency communication system.** Comprehensive emergency communication systems are needed to warn people and to specify actions to be taken in the event of a hazard. Emergency communications systems should utilize all available media outlets including mobile phones, cable television, and the Internet. Technology should be in place to deliver the messages in all locations no matter how remote, and to provide location-specific information. Messages should be crafted based on knowledge of likely human responses and should be provided by a recognizable authority in the given field (e.g., public health officials should provide public health messages). The seriousness of the threat must be conveyed and real-time information must be provided as hazard scenarios evolve.

**Develop policies that promote risk-wise behavior and are based in social science research.** Effective communications for eliciting appropriate public response to hazards must be developed from behavioral, population, and other social science studies. Research should lead to public awareness of the effectiveness of individual and institutional mitigation actions. Research is needed to better understand why people might expose themselves to hazards and what would motivate people to avoid hazards or take mitigating actions before and during a disaster.

To meet this Grand Challenge, the following key research requirements and major technology investments also must be addressed:

**Key research requirements:** Facilitate research in the social sciences to understand and promote individual and institutional mitigation actions in the face of hazards. ■ Develop an enhanced understanding of effective techniques for educating the public and gaining community support for preparedness and disaster prevention activities. ■ Research the effectiveness of, and human responses to, new communications technologies, including mobile phones, the Internet, and cable television on the delivery and successful use of public warnings.

**Major technology investments:** Design and implement a standardized messaging system for the general public and specific audiences. ■ Assemble and coordinate an integrated emergency communications system among response organizations at the Federal, state, and local levels.



# The Way Forward

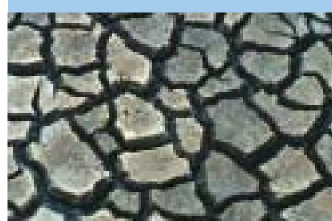
Sustained Federal investment in the Grand Challenges for Disaster Reduction will be facilitated in three stages: *Grand Challenges for Disaster Reduction (June 2005)*. This document provides an overview of the hazard vulnerabilities facing America and identifies the ten-year priorities for focused Federal investment in science and technology for disaster reduction.

*The Five-Year Strategy (Spring 2006)*. This document will be implemented through the annual budgets of the science and technology agencies conducting appropriate research and development.

*Annual Implementation Plans (2007 and beyond)*. The final stage in this process is the implementation of The Five-Year Strategy through the annual budgets of the science and technology agencies conducting the appropriate research and development. This implementation will entail a series of annual recommendations regarding Federal program planning and funding.

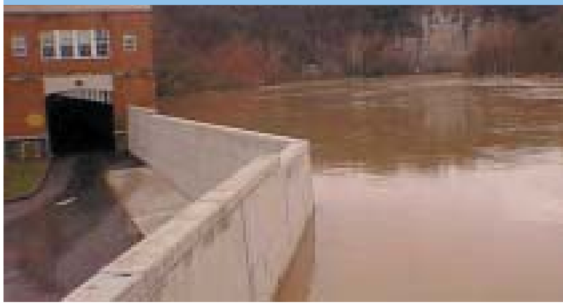
Together, the *Grand Challenges for Disaster Reduction* document, *The Five-Year Strategy*, and the annual implementation recommendations provide an evolving framework for Federal investments that enhance the Nation's disaster resilience.

## Disaster Profile: **Drought**



Drought is a persistent and abnormal moisture deficiency, having adverse effects on vegetation, animals, or people. Slow-onset, non-structural impacts and lack of a uniform definition make drought a unique natural hazard. Compared to all natural hazards, droughts are, on average, the leading cause of economic losses. The estimated cost of the 1988–1989 drought was $39 billion nationwide and was, at the time, the greatest single year hazard-related loss ever recorded.[21] In 2004, many Western states experienced their fifth consecutive year of drought and one of the worst droughts of the past century.

The slow onset of drought over space and time can only be identified through the continuous collection of climate and hyrodologic data. To enhance decisions and minimize costs, drought warning systems must provide credible and timely drought risk information including drought monitoring and prediction products.



# Conclusion

We cannot avoid hazards, but we can act to minimize and reduce their impacts. After all, hazards do not become disasters unless the communities they touch are unprepared to deal with them. In short, disaster resilience must become inherent to our national culture and a natural right of all people. This report establishes a framework for Federal investment in science, engineering, and technology to reduce America's disaster vulnerability. Successfully reducing disasters depends upon sustained investment in these Grand Challenges and in recognizing that hazards are inherent on our complex environmental, constructed, agricultural, political, and social systems.

*Aftermath of Hurricane Fran, September 1996, Photograph by Dave Gatley, from FEMA Photo Library*

# Appendix A: Research Requirements and Technology Investments by Hazard

## Grand Challenge 1: Provide Hazard and Disaster Information Where and When It Is Needed.

**Drought.** Improve the information infrastructure to reach and educate those affected by drought and those providing drought information.

**Earthquake.** Continue to deploy and maintain modernized and expanded systems to collect data for use in the prediction of earthquake occurrences and their effects.

**Flood.** Develop improved hundred-year flood plain maps. ■ Develop flood risk maps based on future development of watersheds so that maps stay current and property owners understand how development impacts their vulnerability and risk.

**Public Health/Environmental.** Identify mechanisms and processes and corresponding prevention or reduction strategies for health and ecological impacts.

**Severe Weather.** Accelerate development of integrated data observation systems, models, and forecast platforms to reduce the area placed under warnings and to reduce costly and unnecessary evacuations. ■ Capture and use improved remotely sensed observations in high space and time resolution of atmospheric and land surface data over the entire globe. ■ Use improved observational, assimilation, and modeling techniques, such as four-dimensional, high-time, and space resolution observations of atmospheric moisture.

**Technological.** Develop GIS databases at local, state, and national levels to map critical infrastructure, industry, public health services, and other facilities in order to identify locations of technological disasters, and predict the direction and extent of damage.

**Volcano.** Build a database of hazard/volcanic history information, as well as information on population placement and local facilities (highways, dams, airports, etc.) that could be impacted by different types of eruptions.

**Wildland Fire.** Increase the emphasis on space-based thermal fire detection, monitoring, and mapping capabilities. More fully integrate information across hazards to identify and illustrate interactions, including environmental benefits of natural wildland fires (e.g., relationships of drought to potential fire severity, and then to the extended risk of flooding after a catastrophic wildland fire).

## Grand Challenge 2: Understand the Natural Processes That Produce Hazards.

**Drought.** Build and deploy a national instrument system capable of collecting climate and hydrologic data to ensure drought can be identified spatially and temporally. ■ Develop an integrated modeling framework to quantity predictions of drought and drought impacts useful in decision making.

**Earthquake.** Improve earthquake hazard assessments to include the effects of local soil conditions, local geologic structures, earthquake mechanics (e.g., directivity and stress drop) and recent seismic activity, and to provide estimates of the uncertainty. ■ Develop improved realistic and reliable models of fault and earthquake processes including strain accumulation and earthquake nucleation, fault rupture and arrest, and seismic wave generation and propagation.

**Flood.** Project real-time flood hazard impacts for large and small basins. ■ Develop improved real-time models that capture the interdependencies of floods. ■ Develop enhanced models for rapid assessment of stream stability. ■ Improve sensor network design and operational capabilities to provide early data needed for predicting and sensing hazards using physical process models.

**Public Health/Environmental.** Improve disease and environmental monitoring to identify, describe, collect, analyze, and interpret emerging infectious and environmental agents (e.g., organisms, toxic substances, etc.). These monitoring systems must be accurate and specific, particularly for threat agents. ■ Integrate biological, physical, and chemical models to provide accurate and timely forecasts.

**Severe Weather.** Develop models to better forecast and track intensity changes of tropical storms and associated impacts (e.g., storm surge, inland flooding and tornado outbreaks).

**Technological.** Develop real-time contaminant-specific detectors, alarm systems, and data analysis tools. ■ Study the basic mechanisms behind contaminant fate and transport in air, water, and through the earth.

**Volcano.** Incorporate real-time monitoring of all active volcanoes at a level appropriate to the risk they pose. ■ Build models for distribution of erupted products. ■ Develop models that incorporate data on seismicity, deformation, gravity changes, gas emissions, magma movement, and other parameters to distinguish between magmatic and geothermal unrest—seismic tomography evaluation of magma reservoirs.

**Wildland Fire.** Improve understanding of the processes of wildland fire behavior, fuel development, and condition at a landscape scale—and interactions between these factors and weather and climate at regional to global levels—to accurately model and predict the potential occurrence, behavior, and impacts of wildland fire on resources, on the environment, and on physical infrastructure.

## Grand Challenge 3: Develop Hazard Mitigation Strategies and Technologies.

**Drought.** Develop decision support tools that proactively reduce the potential severity of drought impacts. ■ Incorporate drought monitoring and prediction products into mitigation plans in time to make changes to natural resources planning.

**Earthquake.** Use scientific research to develop appropriate building/design code provisions to mitigate progressive collapse vulnerability following earthquake, wildland fire, or other events, including earthquake-triggered landslides. ■ Improve understanding of building response to strong shaking through large-scale laboratory testing and instrumentation of buildings for real-time monitoring.

**Flood.** Identify and mitigate impacts of development in community plans before development occurs. ■ Provide transportable and easily installed flood mitigation systems to support flood fights.

**Public Health/Environmental.** Model outcomes of known and predictable natural and technological hazards on at-risk populations and ecosystems in specific geographic areas. ■ Develop environmental decontamination capabilities for chemical, biological, radiological, and hazardous substances.

**Severe Weather.** Integrate knowledge of the climatology of local meteorology into building codes, the location of new development, populations, and materials.

**Technological.** Improve response and planning capabilities, to include the use of contingency plans. ■ Develop improved, security based design standards for new facilities, transportation containers, and storage devices.

**Volcano.** Institute a practice in which land use planners incorporate information from volcano hazard maps in their projects as appropriate.

**Wildland Fire.** Implement integrated landscape level wildland fire management plans for all Federal and state agencies and for all lands based on detailed risk analysis. ■ Design and evaluate building material with improved wildland fire safety characteristics.

## Grand Challenge 4: Recognize and Reduce Vulnerability of Interdependent Critical Infrastructure.

**Drought.** Collect information to support policies that restore urban and rural communities in a manner that reduces long-term vulnerability to critical infrastructures while enhancing resilience.

**Earthquake.** Develop performance criteria based on actual infrastructures, research, and other work for design and retrofit methods.

**Flood.** Understand land-use measures and the cumulative impacts on the hydrology and hydraulics of flooding and drought. ■ Thoroughly develop evacuation plans for flood plains. ■ Identify the potential impact of flooding on water, waste-water, and sewer systems, and make them more resistant.

**Public Health/Environmental.** Assure that access to hospitals and emergency medical services is maintained following hazard events.

**Severe Weather.** Improve development of appropriate response, contingency, and evacuation community plans based on knowledge of extreme weather events derived from long-term data collection and analysis. ■ Develop or identify cost-effective technologies that ensure that critical utilities and other infrastructure survive severe weather events.

**Technological.** Develop more advanced computational models for the design and evaluation of mitigation methods and strategies for all types of infrastructures and industries. ■ Automate regional GIS-based emergency response plans and integrate plans from industry, critical infrastructure and resources, and local communities.

**Volcano.** Develop evacuation plans and incorporate in all community response plans.

**Wildland Fire.** Research wildland fire safe practices (e.g., fuel management in interface zones) in all communities either voluntarily or in response to regulatory action. ■ Improve wildland fire hazard assessment methods for communities in the wildland-urban interface to include community and building design and the logistics of access and egress for disaster responders.

## Grand Challenge 5: Assess Disaster Resilience Using Standard Methods.

**Drought.** Provide drought relief based on real-time information on the extent and intensity of drought events around the globe. ■ Develop standards for assessment of social and economic costs of direct and indirect drought impacts.

**Earthquake.** Extend the computational models to serve as a tool for recovery planning and incorporate them into mitigation strategies. ■ Collect cost-benefit information on the value of monitoring and notification capabilities.

**Flood.** Facilitate immediate analysis of flood parameters following disaster so as to assist recovery operations and restoration or removal of impacted facilities.

**Public Health/Environmental.** Develop and institute recovery programs for human and animal health (e.g., injury rehabilitation, mental recovery, suicide prevention, domestic violence, water system evaluation, safety of food, vector control, epidemiological monitoring, etc.). ■ Develop pilot projects for recovery and restoration techniques (e.g., replanting of multiple species in areas decimated by diseases or parasitic invasion, diagnostic tools for mental health).

**Severe Weather.** Coordinate inter-agency, detailed post-storm assessment of damage, injuries, and deaths.

**Technological.** Design a suite of new non-invasive, environmentally sound, and rapidly deployable clean-up technologies for contaminated soil, water, and built surfaces. ■ Identify and implement new disposal and waste reduction techniques.

**Volcano.** Disseminate information to communities surrounding volcanoes regarding the removal of volcanic ash, timeline for return to evacuated areas after an eruption; and potential hazards that exist after an eruption. ■ Make information available to the public and to emergency responders regarding post event recovery operations, decontamination efforts, and the post-hazard environment.

**Wildland Fire.** Extend awareness and response and warning systems that address possible post-catastrophic fire events such as debris flows. ■ Anticipate recovery in advance based on model predictions of wildland fire effects and an understanding of effectiveness of both natural regeneration and post-fire emergency rehabilitation treatments and restoration treatments at reducing damage to ecosystems and water resources from wildland fires.

## Grand Challenge 6: Promote Risk-Wise Behavior.

**Drought.** Implement a drought warning system capable of providing credible and timely drought risk information to enhance decisions and minimize costs associated with drought.

**Earthquake.** Create a uniform and reliable alert system; including consistent classification schemes for disaster severity. ■ Predict effects, impacts, and cascading failures of an earthquake as the event is occurring and deliver the information in the first five to ten minutes after the event. ■ Develop automated early-warning systems capable of reducing impact to critical infrastructure in urban centers at a distance from the earthquake epicenter. ■ Improve real-time communication between the weather-forecasting community and earth science community responsible for landslide warnings.

**Flood.** Develop integrated, area-targeted, multi-media systems for issuing warnings on flash floods and other rapid on-set disasters. ■ Use social science research to coordinate public education to help people understand and respond to warnings. ■ Institute a practice in which land use planners incorporate information from flood and landslide hazard maps in their projects, as appropriate.

**Public Health/Environmental.** Develop and improve communication of warnings for health and environmental hazards. ■ Evaluate the scientific basis for individual actions before, during, and after an event to reach inter-agency agreement on best practices.

**Severe Weather.** Direct automated calls (e.g., reverse 911) to those at risk. ■ Accelerate improvements in predictive models through enhanced physical understanding, data assimilation, and spatial resolution.

**Technological.** Facilitate a scientifically literate national and local media to report on the facts behind technological disasters, including their impacts and ways by which the public can mitigate effects. ■ Improve rapid risk assessment methods for providing immediate public health information during a disaster.

**Volcano.** Develop a standardized messaging system for use by the general public and specific audiences (e.g., the FAA).

**Wildland Fire.** Improve development and implementation of effective and accessible communication systems to inform the public of the impacts of policy alternatives, weather, insect and disease infestation, human actions and other factors on risks to communities, ecosystems, and environment from wildland fire. Also, implement communication systems for effective, proactive community involvement in risk analysis and decision making. ■ Develop communication capabilities that enable complete and timely use of tools for assessment and planning. ■ Integrate real-time weather information with hazard warning systems, (e.g., linking precipitation forecasts with post-fire debris flow warnings.)

# Appendix B: Key Terms

**All-hazards approach**—an integrated hazard management strategy that incorporates planning for and consideration of all potential natural and technological hazards, including terrorism.

**Built environment**—the Nation's constructed facilities, buildings, transportation, and industrial infrastructure systems.

**Critical infrastructure**—the physical and cyber-based systems that are essential to the minimum operations of the economy and government.

**Disaster**—a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources.

**Disaster risk**—the chance of a hazard event occurring and resulting in disaster.

**Hazard**—a natural or human-caused threat that may result in disaster when occurring in a populated, commercial, or industrial area.

**Hazard event**—a specific occurrence of a hazard.

**Hazard mitigation**—any action taken to reduce or eliminate the long-term risk to human life and property from natural hazards.

**Hazard risk**—the chance of a hazard event occurring.

**Natural disaster**—a disaster that results from a natural hazard event.

**Natural hazard**—a hazard that originates in natural phenomena (e.g., hurricane, earthquake, tornado).

**Resilience/resilient**—the capacity of a system, community, or society potentially exposed to hazards to adapt, by resisting or changing, in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures.

**Risk**—the probability of harmful consequences or expected losses (death and injury, losses of property and livelihood, economic disruption, or environmental damage) resulting from interactions between natural or human-induced hazards and vulnerable conditions.

**Technological disaster**—a disaster that results from a technological hazard event.

**Technological hazard**—a hazard that originates in accidental or intentional human activity (e.g., oil spill, chemical spill, building fires, terrorism).

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# Appendix D: About the National Science and Technology Council

## About the National Science and Technology Council

The National Science and Technology Council (NSTC), a cabinet-level council, is the principal means for the President to coordinate science and technology policies across the Federal Government. NSTC acts as a virtual agency for science and technology to coordinate the diverse parts of the Federal research and development enterprise.

An important objective of the NSTC is the establishment of clear national goals for Federal science and technology investments in areas ranging from information technologies and health research to improving transportation systems and strengthening fundamental research. This council prepares research and development strategies that are coordinated across Federal agencies to form an investment package aimed at accomplishing multiple national goals.

To obtain additional information regarding the NSTC, contact the NSTC Executive Secretariat at (202) 456-6101.

## About the Committee on Environment and Natural Resources (CENR)

The purpose of the Committee on Environment and Natural Resources (CENR) is to advise and assist the NSTC to increase the overall effectiveness and productivity of Federal research and development efforts in the area of the environment and natural resources. This includes maintaining and improving the science and technology base for environmental and natural resource issues, developing a balanced and comprehensive research and development program, establishing a structure to improve the way the Federal Government plans and coordinates environmental and natural resource research and development in both a national and international context, and developing environment and natural resources research and development budget crosscuts and priorities.

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## About the Subcommittee on Disaster Reduction

Mitigating natural and technological disasters requires a solid understanding of science and technology, rapid implementation of research information into disaster reduction programs and applications, and efficient access to diverse information available from both public and private entities. The Subcommittee on Disaster Reduction provides a unique Federal forum for information sharing, development of collaborative opportunities, formulation of science- and technology-based guidance for policy makers, and dialogue with the U.S. policy community to advance informed strategies for managing disaster risks.

Chartered in 1988, the Subcommittee on Disaster Reduction is a subcommittee of the Committee on Environment and Natural Resources, an element of the President’s National Science and Technology Council. The Chair, the Vice Chair for Policy, and the Vice Chair for Science and Technology are each selected by the White House Office of Science and Technology Policy and serve a three-year term. The heads of relevant agencies and departments annually designate lead representatives to the SDR.

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# Grand Challenges Summary

## Provide Hazard and Disaster Information Where and When It Is Needed.

- Improve data collection to increase understanding of the ways in which hazards evolve.
- Create standards for sharing, storing, and analyzing data.

## Understand the Natural Processes That Produce Hazards.

- Improve models and visualization techniques.

## Develop Hazard Mitigation Strategies and Technologies.

- Create resilient structures and infrastructure systems using advanced building technologies.
- Support structural advances with effective nonstructural mitigation.
- Quantify the monetary benefits of disaster mitigation using economic modeling.

## Recognize and Reduce Vulnerability of Interdependent Critical Infrastructure.

- Develop science and technology to prevent cascading failures in public infrastructure systems.
- Enhance the ability to protect public health before and after a hazard event.

## Assess Disaster Resilience Using Standard Methods.

- Support intelligent community planning and investment strategies and protect natural resources with comprehensive risk assessments.
- Assess the resilience of the natural and human environment.
- Learn from each hazard event.

## Promote Risk-Wise Behavior.

- Raise public awareness of local hazards.
- Warn people with consistent, accessible, and actionable messages and a national all-hazards emergency communication system.
- Develop policies that promote risk-wise behavior and are based in social science research.

# Grand Challenges *for* Disaster Reduction

A Report of the
Subcommittee on Disaster Reduction