Science and Technology Policy Institute

Assessing Federal Research and Development for Hazard Loss Reduction

CHARLES MEADE

MEGAN ABBOTT

Prepared for the
Office of Science and Technology Policy

RAND

The research described in this report was conducted by RAND's Science and Technology Policy Institute for the Office of Science and Technology Policy under contract ENG-9812731.

Library of Congress Cataloging-in-Publication Data

Meade, Charles.
Assessing federal research and development for hazard loss reduction / Charles Meade and Megan Abbott.
p. cm.
"MR-1734".
Includes bibliographical references.
ISBN 0-8330-3442-1 (pbk.)
1. Natural disasters—United States. 2. Emergency management—Research—United States. 3. Environmental risk assessment—United States. 4. Earthquakes—United States. I. Abbott, Megan E., 1971– II. Title.

HV555.U6M43 2003
362.34'6—dc21

2003013083

Published 2003 by RAND
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
201 North Craig Street, Suite 202, Pittsburgh, PA 15213-1516
RAND URL: http://www.rand.org/
To order RAND documents or to obtain additional information, contact Distribution Services: Telephone: (310) 451-7002; Fax: (310) 451-6915; Email: order@rand.org

PREFACE

Losses resulting from natural hazards are a large and growing problem in the United States. While attention tends to focus on the problems that immediately follow devastating floods, hurricanes, earthquakes, and wildfires, the ongoing costs to the U.S. economy are enormous, on the order of hundreds of millions of dollars each week.

Broad efforts to address this problem are in place across the federal government. Within the White House, the Office of Science and Technology Policy (OSTP) plays a key role in coordinating the research and development policies upon which the technical response to hazard losses is based. To support OSTP in this task, RAND carried out a comprehensive analysis of current hazard loss R&D funding, identifying programs and activities that contribute to hazard loss reduction. The analysis addressed the following questions:

- What is the distribution of federal R&D funding across various hazards and across areas of focus (prediction, infrastructure improvements, mitigation techniques)?
- What criteria determine the allocation of these funds?
- How do these R&D efforts contribute to hazard loss reduction?

This report presents the analysis and its findings, along with a number of policy recommendations for increasing the effectiveness of current R&D efforts.

About the White House Office of Science and Technology Policy

The Office of Science and Technology Policy was created in 1976 to provide the President with timely policy advice and to coordinate the federal investment in science and technology.

About the Science and Technology Policy Institute

Originally created by Congress in 1991 as the Critical Technologies Institute and renamed in 1998, the Science and Technology Policy Institute is a federally funded research and development center sponsored by the National Science Foundation and managed by RAND. The Institute's mission is to help improve public policy by conducting objective, independent research and analysis on policy issues that involve science and technology. To this end, the Institute

- Supports OSTP and other Executive Branch agencies, offices, and councils.
- Helps science and technology decisionmakers understand the likely consequences of their decisions and choose among alternative policies.
- Helps improve understanding in both the public and private sectors of the ways in which science and technology can better serve national objectives.

In carrying out its mission, the Institute consults broadly with representatives from private industry, institutions of higher education, and other nonprofit institutions.

Inquiries regarding the Science and Technology Policy Institute may be directed to

Helga Rippen, Ph.D., MD, MPH
Director
Science and Technology Policy Institute

CONTENTS

FIGURES

TABLES

SUMMARY

In recent decades, the United States has experienced a decline in the numbers of lives lost due to natural hazards such as earthquakes, hurricanes, floods, and droughts. At the same time, the associated costs of these events are escalating. Between 1978 and 1989, the Federal Emergency Management Agency (FEMA) paid out about $7 billion in disaster relief funds. In the next dozen years, however, payouts increased almost fivefold, to over $39 billion.[1]

The primary cause of the rise in losses appears to be the growing population in areas that are vulnerable to natural hazards. Demographic changes, most dramatically, the mass human migration to coastal and other high-risk areas, have made hazards increasingly costly events—the more people and property in vulnerable areas, the more hazard damages. In addition, these growing high-concentration pockets of both people and property contribute to an escalation in the complexity of the nation's infrastructure—public utilities, critical facilities, transportation systems, communications networks, the built environment. As the density of the infrastructure increases, particularly in urban areas, the potential losses from natural hazards become greater still.

Because of the heavy financial burden imposed by these losses across all sectors of the economy, pressure on the federal government to act quickly and effectively to "solve" the problem has been growing. With this motivation, the federal strategy to address the hazard loss problem takes many forms, from providing disaster relief to assisting in the regulation of private insurance to encouraging mitigation efforts through various incentives. A key weapon in the federal government's arsenal is its support of research and development (R&D). Specifically, it funds work carried out by the research community to improve understanding of, preparation for, and response to hazards and their impacts.

PURPOSE OF THE STUDY

To formulate a better understanding of the role of government-sponsored R&D in the nation's efforts to reduce hazard losses, the Office of Science and Technology

[1]These amounts are in fiscal year (FY) 2001 dollars. According to the General Accounting Office (GAO), this rise is attributable to both a "number of large, costly disasters" and the fact that "activities eligible for federal assistance have increased" (GAO, 2002).

Policy (OSTP) asked RAND to conduct an analysis of the full range of federal R&D expenditures related to hazard loss reduction. The following questions guided the analysis:

- What is the distribution of federal R&D funding across various types of hazards?
- What types of research activities are supported by federal funding?
- What criteria determine the allocation of these funds?
- How do these R&D efforts contribute to hazard loss reduction?

The analysis provides an approach for determining whether there are holes or imbalances in the federal R&D portfolio and whether key areas are being overlooked. The results will contribute to the development of a policy framework that will help in future attempts to assess the "payoffs" of various kinds of R&D, including which efforts offer the greatest potential for reducing hazard losses. Finally, the analysis leads to larger issues about the demands placed on R&D to "solve" the problem of hazard losses. Ultimately, we offer suggestions for new ways to frame expectations and demands for R&D in addressing the problem of hazard losses.

METHOD

To answer the questions posed by OSTP, we needed to generate a clearer view of the hazard loss reduction efforts in the current federal R&D portfolio. We therefore conducted an analysis of the federal R&D portfolio for a particular year, FY 2001. Our goal was to identify R&D expenditures that support the goals of reducing losses from natural hazards such as floods, hurricanes, earthquakes, and wildfires.

Because the federal budget does not have a separate R&D budget, much less one focused solely on hazard loss, we had to develop a set of detailed criteria to identify hazard loss R&D activities within larger research programs across the federal government. Our data sources were RAND's RaDiUS database and other sources of federal budget information. The RaDiUS database details all federal R&D funding as determined by computer records from the Office of Management and Budget (OMB). We also looked at individual agency budget requests, as well as annual R&D reports generated by the Office of the Federal Coordinator for Meteorology, which encompasses the broad range of weather-related federal programs.

MAIN FINDINGS

Using these sources, we were able to analyze funding from a number of perspectives, quantifying expenditures by agency, hazard type, and program goals. Our key findings were as follows:

- *Explicit hazard loss reduction programs receive the least funding.* Programs dedicated solely to hazard loss reduction R&D receive the smallest share of R&D funds. The largest fraction goes to basic and applied research programs at the National Science Foundation (NSF), the National Oceanic and Atmospheric

Administration (NOAA), and the National Aeronautics and Space Administration (NASA). The second largest category is operational support R&D, focused almost exclusively on weather-related hazards.

- *The largest fraction of R&D spending supports work on weather hazards and broadly related research on climatology, atmospheric science, and oceanography.* The second largest category of R&D funding—a distant second—is research on earthquakes. While losses from weather-related hazards are estimated to be approximately twice as large as those from earthquakes, the allocation of R&D funds between these categories differs by more than a factor of 10.
- *Much of the R&D spending supports short-term prediction capabilities.* Closer examination of the funding for weather-related hazard R&D shows that most of the effort is focused on short-term prediction efforts, which have limited loss reduction potential within the full range of losses from natural hazards. Prediction can generally move individuals out of harm's way, but R&D focused on long-term loss reduction strategies could improve the resilience of communities and infrastructure, protecting lives and property in a far more substantial way.

CHALLENGES FACING POLICYMAKERS

This emphasis on weather-related hazards and prediction means that other areas of hazard R&D receive comparatively less attention. However, decisionmaking in this policy environment is difficult. Despite its investments in hazard loss reduction R&D, the government has yet to establish the essential framework that would enable these efforts to operate efficiently and show their own merit. Developing a more thoughtful strategy for funding allocation depends on the ability to accurately determine the losses resulting from hazards and the losses prevented or reduced by R&D efforts. In turn, it also depends on the willingness of individuals and communities to implement measures designed to reduce hazard losses. In other words, decisionmakers face both quantitative and qualitative challenges in seeking to strengthen the effectiveness of federal hazard loss R&D efforts.

First and foremost among these challenges is the lack of detailed data on losses from natural hazards. (This quantitative gap has been identified and examined in a number of previous policy studies.) Without such data, it is impossible to gauge either the effectiveness of new R&D strategies or their ultimate payoff in terms of losses prevented. Detailed loss data would go a long way toward enabling a more cost-effective distribution of R&D funds.

From a qualitative standpoint, perhaps the most daunting obstacle policymakers face is human nature. Human behavior ultimately controls the scale of disaster losses and thus exerts a major force on R&D policy decisions for hazard loss reduction. While R&D provides useful technical information, its effectiveness is determined by human decisionmaking on issues such as whether to evacuate, where to locate new construction, and whether to implement known mitigation measures in existing communities.

FIRST STEPS TO IMPROVING THE R&D CONTRIBUTION

To address these problems, we recommend the following key steps for decisionmakers:

- *Establish a comprehensive national loss database.* Data on hazard losses are central for a host of concerns, including prioritizing R&D efforts, planning budgets for states and localities, developing contingency operations, and conducting cost-benefit analyses for specific measures that will allow policymakers to see the relative value of various R&D efforts and will help citizens to understand the value of implementing long-term mitigation procedures.
- *Utilize loss modeling to identify essential R&D.* Loss modeling, which simulates the impacts of potential disasters, can help determine which hazards generate the greatest avoidable losses, the effects of mitigation steps on loss totals, the time scale for losses, and the budget needs for vulnerable regions to prepare for a prospective hazard. These models hold great promise for prioritizing research needs by weighing the costs and benefits of various mitigation measures against the estimated losses from specific hazards.
- *Reorient R&D activities toward longer-term loss reduction efforts*. A shift to longer-term, less prediction-oriented efforts holds great potential for reducing losses. The development of technologies to strengthen the built environment can save lives, protect property, and dramatically reduce the costs of rebuilding after a disaster.
- *Increase the focus on technologies and information that will reduce infrastructure losses*. Damage to infrastructure—e.g., buildings, public roads and highways, bridges, water and sewer treatment plants, and emergency services—results in casualties as well as extensive economic losses. The development of improved technologies and information systems can help limit such losses. For instance, greater R&D focus on funding for communications and remote sensing capabilities, geographic information and global positioning systems (GPSs), and modeling and simulation techniques should lead to considerable damage reduction.

While these steps are critical, they essentially constitute improvements to the existing R&D effort. They do not address perhaps the most fundamental obstacle to the success of the R&D contribution to hazard loss reduction: Whether the right questions are being asked of R&D. In the face of rising hazard costs and increasing societal vulnerability, what exactly is it that R&D is expected to do?

A NEW FRAMEWORK FOR R&D

Ultimately, the increase in hazard losses is a societal problem, driven and exacerbated by human will—the desire to live on coastlines and other hazard-prone areas, to create increasingly complex infrastructure, to continue to expand the built environment, and to rely on short-term predictions to avoid oncoming hazards rather than preparing in the long term for hazard potentialities.

These societal factors, in combination with gaps in quantitative data and the limits of science's ability to produce completely accurate predictions, create a highly complicated and volatile environment in which R&D must operate. Given this environment, it should come as no surprise that current hazard loss reduction efforts—and the role of R&D within them—are haphazard and uncoordinated. Indeed, in the face of the array of forces at play, it is not clear at all that government can "solve" the problem of rising hazard losses as that problem is currently framed.

Thus we propose a rethinking of the demands placed on R&D. Specifically, we offer an alternative framework for considering the problem being laid at the feet of hazard loss R&D. This framework consists of a series of parameters that should be considered when configuring the role of R&D in addressing a problem such as hazard losses:

- *R&D should be designed for straightforward implementation.* Specifically, the R&D problem should be framed in a way that allows the findings to be put into practice. Findings should lead, for example, to evacuation improvements, measurements of hazard phenomena that can be incorporated into engineering studies, and loss modeling that can be incorporated into mitigation plans.
- *R&D should be focused on solvable problems.* Even science has its limits. For instance, it is unlikely that it will ever be possible to predict the time and place of earthquakes. R&D decisions must be approached with a clear view of the kinds of knowledge that can be gained through research efforts and the kinds of knowledge that simply cannot be grasped given inherent uncertainties.
- *Expectations for the role of discovery should be clear.* There should be agreement as to the expectation that a major, unpredicted discovery may emerge that will transform the state of science in a given area.
- *Progress should be identifiable.* If the effort carries no expectation of or desire for unanticipated discovery, then researchers should be operating with an eye to a specific end goal or at least to signposts along the way. When progress is identifiable, the ultimate contributions will be clearer.

* * * * *

Obstacles both practical and philosophical have stood in the way of a more successful hazard loss R&D strategy. But if a few key steps are taken toward improving the ability of policymakers to make informed decisions about hazard R&D, significant rewards are likely to be realized in the form of a more comprehensive national strategy to reduce hazard losses.

ACRONYMS

CMS	Division of Civil and Mechanical Systems
DOC	U.S. Department of Commerce
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FS&T	federal science and technology
FY	fiscal year
GAO	General Accounting Office
GIS	geographic information system
GPS	global positioning system
HAZUS	Hazards U.S. (methodology for estimating earthquake losses)
HHS	Department of Health and Human Services
IPCC	Intergovernmental Panel on Climate Change
MTPE	Mission to Planet Earth
NAHB	National Association of Home Builders
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NEHRP	National Earthquake Hazards Reduction Program

NESDIS	National Environmental Satellite Data and Information Service
NFIP	National Flood Insurance Program
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSF	National Science Foundation
NSTC	National Science and Technology Council
NWR	Weather Radio Network
OFCM	Office of the Federal Coordinator for Meteorology
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
OTA	Office of Technology Assessment
PART	Program Assessment Rating Tool
R&D	research and development
S&T	science and technology
SBA	Small Business Administration
SDR	Subcommittee on Disaster Reduction
SNDR	Subcommittee on Natural Disaster Reduction
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

Chapter One

INTRODUCTION AND BACKGROUND

In recent years, the United States has experienced a decline in the number of lives lost as a result of natural hazards. At the same time, the associated economic costs of these events—both atmospheric (hurricanes, tornadoes, winter storms, heat, droughts, and floods) and geologic (volcanoes, earthquakes, landslides, and tsunamis)—are escalating.[1] Between 1978 and 1989, Federal Emergency Management Agency (FEMA) disaster relief fund expenditures totaled about $7 billion. In the next dozen years, however, that number increased almost fivefold, to over $39 billion (GAO, 2002).[2] The costs of weather-related disasters have doubled or tripled each decade over the past 35 years (Mileti, 1999, p. 66).[3] During the 1990s, an estimated $13 billion in losses resulted each year from extreme-weather events (Pielke and Carbone, 2002).[4] Examples of these trends are charted in Figures 1.1 through 1.3, which show federal disaster relief payments and losses from U.S. hurricanes.

The United States has made great strides in its ability to protect its citizens during disasters. Compare, for instance, the 1995 Kobe earthquake in Japan to California's 1994 Northridge earthquake. With a 6.9 magnitude, the Kobe earthquake caused an estimated $200 billion in damage, and more than 5,000 lives were lost. The Northridge earthquake, with a magnitude of 6.7, caused over $40 billion in damage but resulted in the loss of only 59 lives. Building code improvements and other efforts to sustain infrastructure are widely believed to have played an important role in limiting casualties.

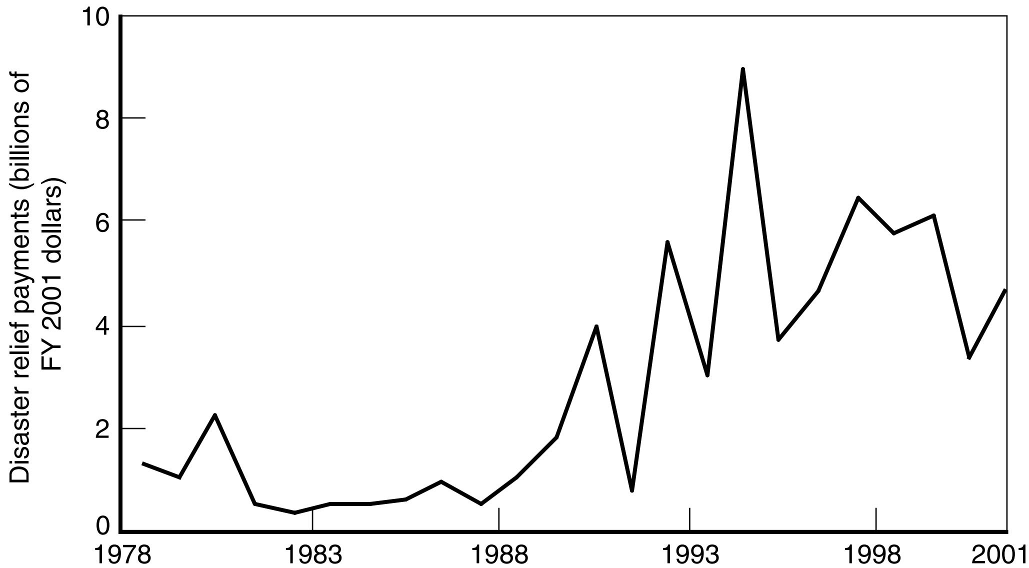
---

[1]While we use the terms *hazard* and *disaster* interchangeably here, many federal agencies and other entities distinguish between them. Generally, a natural hazard is characterized as a natural phenomenon that has the potential to cause damage to individuals, the environment, and property, whereas a disaster is on a larger scale in terms of impact, generally exceeding people's ability to control or recover quickly or completely from its consequences.

[2]These amounts are in fiscal year (FY) 2001 dollars. According to the General Accounting Office, this rise is attributable to both a "number of large, costly disasters" and the fact that "activities eligible for federal assistance have increased" (GAO, 2002).

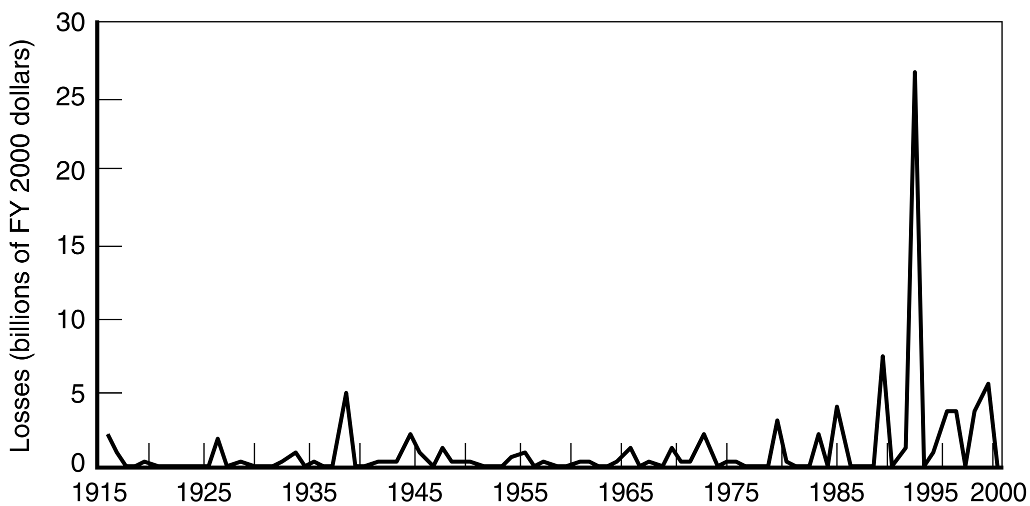
[3]These figures are in FY 1994 dollars standardized on the basis of the Consumer Price Index. All such loss estimates are wide-ranging due to the data limitations outlined in Chapter Four.

[4]Pielke and Carbone (2002) updated figures generated by Kunkel, Pielke, and Changnon (1999), who calculated the economic and other human losses related to extreme weather in the United States. As Pielke and Carbone point out, "Caution is urged in the use of these aggregate figures. Different measures might arrive at smaller or larger results" (p. 395). The difficulties in deriving definitive loss totals are discussed throughout this document.



SOURCES: GAO, 2002; NRC, 1999.

Figure 1.1—Federal Disaster Relief Payments (1978–2001)



SOURCE: Jarrell et al., 2001.

Figure 1.2—U.S. Hurricane Losses (1915–2000)

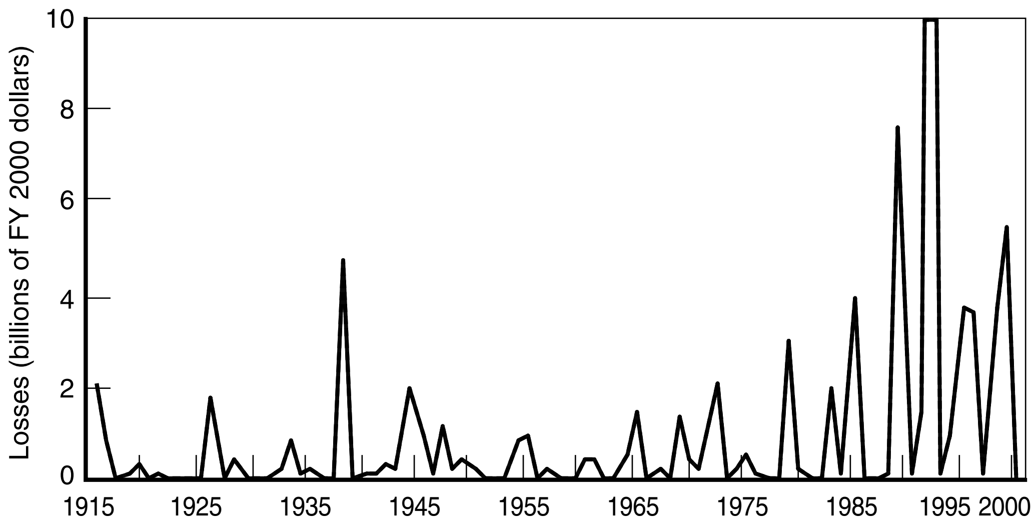


Figure 1.3—U.S. Hurricane Losses (1915–2000), Not Including the Losses from Hurricane Andrew (1992)

Safeguarding individuals is always the highest priority, but progress still must be made toward limiting the mounting economic impact of such events. In addition to the direct damages stemming from the Northridge earthquake, an estimated 3.5 million people experienced the long-term negative consequences of damage to homes, workplaces, schools, public utilities, freeways, and hospitals (Hays, 1995). Moreover, the costs to the federal government were enormous: FEMA, the primary federal source of disaster assistance, paid out roughly $7 billion to victims, with total federal expenditures topping $13 billion.[5] The effects of such large payouts are felt throughout the federal government: FEMA's disaster payments now regularly exceed its appropriations, necessitating supplemental appropriations that may, in turn, result in cuts in other programs or larger deficits.

The question is, Why are the costs of natural hazards rising? If it is possible to shield more and more citizens and, presumably, predict many kinds of hazards with greater and greater accuracy, what is bringing about this precipitous rise in economic losses?

One might speculate that the answer resides in an increase in the incidence and severity of hazards. In particular, recent weather-related losses have led to a rush of concern over whether climate changes are setting off a rise in severe-weather frequency and intensity. A much-discussed 1995 report issued by the Intergovernmental Panel on Climate Change (IPCC) concluded that this was not the case, stating, "Overall, there is no evidence that extreme weather events, or climate variability, has increased in a global sense through the 20th Century, although data and analyses are poor and not comprehensive" (Houghton et al., 1995). The IPCC conclusion is far from definitive, yet it does appear that claims of a dramatic rise in the numbers and

---

[5]According to Petak and Elahi (2000, pp. 11–12), FEMA paid out $6.957 billion of the total $13 billion federal expenditure. The remaining $6.043 billion came from Small Business Administration (SBA) loans and hazard mitigation projects.

intensities of hazards are not generally supportable. The U.S. Geological Survey (USGS) reports that earthquakes of magnitude 7.0 or greater have remained fairly constant in the past century and that there is in fact evidence of a *decrease* in recent years.[6] Likewise, there is significant evidence that the number of intense hurricanes has decreased in the past several decades, as has the number of severe storms. Landsea et al. (1996) point out that public perceptions of a rise in hurricane intensity and frequency likely stem from the enormous damages wrought by disasters such as Hurricane Andrew in 1992, which cost the nation $25 billion. In fact, much of the destruction hurricanes have wrought is due to swelling numbers of coastal residents and the proliferation of property development in coastal areas, both of which contribute heavily to economic losses.

Indeed, many have claimed that the desires and habits of Americans are largely responsible for the rising economic losses. Specifically, population migration to high-risk areas—seismically active regions, remote areas susceptible to wildfires, coastlines—has increased steadily in recent years. More than 50 percent of U.S. citizens now live in coastal areas, where they are vulnerable to flooding and hurricanes (Ward and Main, 1998). Such demographic changes have contributed noticeably to the rise in losses—the more people and property in a high-risk area, the more hazard damages. In addition, the effects of accompanying trends in economic development should not be underestimated. As populations increase in an area, so do the clearing of forests for new homes and businesses, the destruction of wetlands, and the paving of roads and parking lots, all of which increase the runoff from heavy rainfall, putting lives and property at risk. In their literature review on the relationship between economic costs and social trends, Kunkel, Pielke, and Changnon (1999, p. 1094) conclude that the research strongly supports the idea that societal changes are the primary cause of the rise in costs—in particular, coastal and urban population growth, an overall population increase, greater wealth (which means that more expensive goods can be lost), and various lifestyle and demographic changes.

Demographic changes are not solely about growing affluence. Consider the case of mobile-home dwellers. The number of mobile homes has increased significantly in the last half-century, with as many as 10 times more people living in such housing in 1990 as there were in 1950 (Brooks and Doswell, 2001). Mobile homes are at great risk during tornadoes and other severe weather, and the effects of ensuing property damage on these residents can be significant.

In addition to these human factors, technological progress and a general escalation of societal complexity may also contribute to the rise in costs. As Mileti (1999, p. 3) points out, the density of the nation's infrastructure—public utilities, critical facilities, transportation systems, communications networks, the built environment—is increasing, making the potential losses from natural hazards still greater and more sweeping.

[6]According to the USGS Earthquake Hazards Program (2003), the only years since 1971 in which a greater-than-average number of major earthquakes occurred were 1992 and 1995–1997.

THE FEDERAL RESPONSE TO THE PROBLEM

Because hazard losses are large and growing, a great effort has been made to define the roles and responsibilities of the federal government in addressing the problem. Important factors that influence this analysis include the large federal payments of disaster assistance, the government's role in weather forecasting, and the long-standing reliance on government-supported research and development (R&D) to solve social problems. In this environment, the following issues provide a framework for the federal response to the problem of hazard losses.

Responsibility to the nation's citizens. The federal government's commitment to protect its citizens, especially those in need or crisis, is perhaps its foremost consideration in terms of response to natural hazards. Likewise, U.S. legislators have an obligation to their constituencies, as well as a vested political interest, particularly when natural disasters strike directly in their region. Indeed, it is widely recognized that this combination of moral responsibility and political requirements largely drives the process of issuing disaster assistance payments. On a more pragmatic level, abandoning citizens, many of whom may be uninsured or underinsured, to fend for themselves in the wake of floods or hurricanes could have even more widespread economic consequences for the government. When large numbers are impoverished by a disaster, the effects can proliferate, disrupting larger populations and causing ripple effects such as far-reaching public highway or utility disruptions, rising unemployment, and business failures.

Creation of a regulatory environment and promotion of technical resources for a healthy insurance industry. By providing capital, the insurance industry plays a key role in helping communities recover from a natural disaster. Unfortunately, the number of Americans fully insured for the range of natural hazards is small. From 1975 to 1994, only 17 percent of natural hazard losses were insured. Currently, only 20 percent of homes at risk for floods are covered by flood insurance (Mileti, 1999, pp. 66, 168).[7] Furthermore, less than 20 percent of the residences in earthquake-prone areas are insured for earthquakes, down from 30 to 40 percent at the time of the Northridge earthquake (Kunreuther and Roth, 1998, p. 210). Growing weather-related losses have actually placed the private supply of insurance in jeopardy, resulting in many insurance companies withdrawing coverage in disaster-prone areas and capping coverage limits (Changnon et al., 1997, p. 434). Clearly, the federal government could play a role in addressing this problem by promoting an appropriate regulatory environment or supporting technical programs that could be used to establish an actuarial basis for insurance premiums. If successful, these actions could have large implications for hazard loss reduction. In the period before a disaster, the insurance industry could convey important "price signals" to property owners regarding their exposure to hazard risks. In turn, these signals could motivate mitigation actions and construction decisions that would lessen the impact of future hazards.

[7]Mileti cites Property Claim Services, *American Insurance Services Group, Inc. News*, January 14, 1996, as the source for the 17 percent figure.

Creation of incentives to reduce vulnerability. Because of its responsibilities to protect the citizenry and the national economy, the federal government plays a key role in encouraging states and localities to implement hazard loss reduction measures. This encouragement can take the form of grants and assistance conditional on conformity with regulations or on achieving optimal levels of preparation for hazards. For instance, FEMA makes many of its grants contingent on compliance with various land use policies and development restrictions.[8]

Use of science and technology to reduce vulnerability and losses. The role of science and technology in helping forecast, prepare for, understand, and recover from hazards is substantial. The federal government relies heavily on scientific advancements and technological innovation both to respond to hazards and to limit losses. Its commitment to contributing to or leading pioneering science and technological innovation is based on the country's long-standing view of itself as a trailblazer in terms of scientific progress and the application of science to improve the lives of its citizens. This commitment keeps the government's hand in the scientific R&D of new technologies, so that scientific innovation does not rely completely on private industry.

To meet its responsibilities, the federal government has in place an extensive infrastructure dedicated to responding to hazard phenomena. Of particular note for our purposes are the following components of national efforts to reduce hazard losses:

Interagency Subcommittee on Disaster Reduction (SDR). SDR is a subcommittee of the National Science and Technology Council's Committee on Environment and Natural Resources. Consisting of representatives from a range of federal agencies (including FEMA, the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the Environmental Protection Agency (EPA)), SDR is designed to increase interagency cooperation and coordination in hazard assessment, mitigation, and warning.

Robert T. Stafford Disaster Relief and Emergency Assistance Act (1988). The Stafford Act is the law that authorizes federal assistance in response to emergencies and disasters. It also outlines various agency responsibilities, state and local government obligations, and mitigation measures. The Stafford Act requires that hazard mitigation measures under FEMA's hazard mitigation programs (see below) be cost-effective and that they substantially reduce the risk of future damage, hardship, loss, and suffering.

FEMA's mitigation activities. FEMA defines hazard mitigation as any "sustained action taken to reduce or eliminate the long-term risk to people and property from hazards and their effects" (FEMA, 1997, p. 1). In 1995, FEMA unveiled its National Mitigation Strategy to encourage the emergency management community to become more proactive in reducing loss potential in advance of a hazard. Mitigation efforts generally revolve around design and construction, land use planning, organizational

---

[8]Ironically, as an H. John Heinz III Center study points out, many tax incentives have been put in place that *encourage* development in coastal regions, especially on barrier islands (H. John Heinz III Center, 2000, p. 19).

plans, and hazard-control structures (e.g., levees). These activities can include seismic retrofitting, reinforcing highway bridges, ensuring that critical facilities are built to the latest codes, raising levees around water facilities, investing in community wind shutter programs, and establishing local land use ordinances. In 2001, FEMA's Federal Insurance Administration and its Mitigation Directorate were conjoined as the Federal Insurance and Mitigation Administration, which administers a range of grant and assistance programs dedicated to hazard mitigation.

FEMA's National Flood Insurance Program (NFIP). Established in 1968, NFIP offers flood insurance in communities that enforce floodplain management ordinances meeting minimum FEMA criteria, e.g., all residential buildings must be raised above the base flood level. NFIP has also undertaken a $1 billion effort to identify and map the nation's floodplains in order to provide the necessary data to set insurance rates and develop community floodplain management programs. According to NFIP, claims filed since 1978 demonstrate that buildings constructed to minimum standards have sustained 77 percent less damage than those built prior to local enforcement (FEMA, 1997, p. 43).

U.S. Army Corps of Engineers. The Corps conducts emergency response activities as one of its responsibilities. The Stafford Act dictates that the Corps support FEMA in carrying out the Federal Response Plan, which calls on up to 28 federal agencies and the American Red Cross to provide coordinated disaster relief and recovery operations. The Corps also houses its own R&D program, which includes environmental, disaster investigation, and earthquake engineering research programs.

National Earthquake Hazards Reduction Program (NEHRP). NEHRP's mission is to expand knowledge of earthquake hazards and vulnerabilities, improve model building codes and land use practices, reduce risks through post-earthquake investigations and education, develop and improve design and construction techniques, improve mitigation capacity, and accelerate application of research results. These activities are carried out by four agencies: FEMA (the lead agency), NSF, USGS, and the National Institute of Standards and Technology (NIST).

Weather service modernization. Beginning in the late 1980s, the National Weather Service began a 10-year, $4.5 billion modernization effort to increase the accuracy and timeliness of its forecasts and warnings. The centerpiece of the now-complete modernization is the Advanced Weather Interactive Processing System, a state-of-the-art interactive weather computer and communications system that integrates meteorological, hydrological, satellite, and radar data to help improve forecasting capacity and assist forecasters across the country.

THE ROLE OF FEDERAL R&D IN HAZARD LOSS REDUCTION

In this environment, federal R&D is one part of a much larger, coordinated hazard loss endeavor involving policy, implementation, codes, regulations, emergency response, contingency plans, and infrastructure fortification (see Chapter Five for a more detailed discussion of the exact boundaries of the federal role in R&D). However, the R&D contributions to hazard loss reduction should not be underestimated.

R&D provides the necessary knowledge base from which the most effective preparation, prevention, response, operations, and recovery measures are formulated. It also furthers the development of new loss reduction technologies and capabilities and the improvement of existing ones.

The question is, then, Even if R&D is needed, what is the responsibility of the federal government in promoting or supporting it? One might argue that hazard loss R&D belongs in the realm of industry—after all, the private sector now funds almost two-thirds of the nation's R&D efforts (OSTP, 2002). But relying on private-sector funding essentially limits hazard loss R&D activities to entities with a profit incentive. As Eiseman, Koizumi, and Fossum (2002, p. 18) note in their study of the federal R&D investment, "Industry R&D is heavily oriented toward company-specific technology problems and is more focused on development than on the kind of basic research that will provide the foundation for future scientific breakthroughs." Indeed, in 1998, 70 percent of industrial R&D funds were dedicated to the development of products and services rather than to research (National Science Board, 2002).

Thus, although its share of the total R&D funding in this country is declining, the federal government still has a crucial role to play in expanding the knowledge base. Nearly 60 percent of the nation's basic research—the important and often pioneering "pure" research that is conducted without an advanced application in mind—and a comparable share of the R&D activities conducted in U.S. colleges and universities are funded by federal agencies (Eiseman, Koizumi, and Fossum, 2002, p. 18). Likewise, many government priorities and initiatives, such as protecting citizens from natural disasters, would simply not exist without federal support of applied R&D—activities carried out with a specific goal and need in mind.

Thus, a combination of the federal government's important contribution to the national research output and its larger responsibilities to the citizenry makes its role in supporting hazard loss reduction R&D one of ongoing importance. But is the federal investment contributing meaningfully to reducing hazard losses? When the rise in economic losses is considered, is the present federal portfolio sufficient and appropriate? Is it well balanced? Moreover, the larger question eventually emerges: What role is the federal government asking R&D to take in its hazard loss reduction efforts? And is it the right role?

STUDY APPROACH

To explore these issues, we conducted an analysis of the federal R&D effort dedicated to hazard loss reduction. First, we attempted to *quantify* the portfolio. This quantification then enabled us to address a series of key questions about the federal portfolio and its contributions to hazard loss reduction. Specifically, we considered whether there is an appropriate prioritization of funding across hazards (e.g., earthquakes, hurricanes, droughts) and, within hazards, across areas of focus (prediction, infrastructure improvements, mitigation techniques). Inevitably, we had to consider the "all eggs are in one basket" issue. Is too much R&D funding being allocated to one hazard or area of focus? Most private-sector R&D programs operate under a central authority that can coordinate priorities and shift them as needed. The federal R&D

portfolio, however, as Eiseman, Koizumi, and Fossum (2002, p. 12) point out, is determined in a "highly decentralized and uncoordinated manner that makes tradeoffs and priority-setting within the portfolio extremely difficult." In this environment, there is a great risk that spending may not be optimally distributed.

Further, how does the magnitude of the funding in a specific area align with the potential to affect losses? That is, if short-term prediction of floods receives far greater funding, proportionally, than does the capacity to diminish flood losses through short-term warnings, then perhaps the funding allocation needs to be rethought. Likewise, if spending is tilted too far in favor of some areas, other hazards and topics are most certainly receiving comparatively little funding. Our analysis allowed us to consider whether there are gaping holes in the portfolio and whether key areas are dangerously overlooked. In turn, the study enabled us to begin developing a framework to assess the "payoffs" of various kinds of R&D, including which research efforts offer the greatest potential for lessening hazard losses. Finally, our analysis led us to larger questions about the demands placed on R&D to "solve" the problem of hazard losses.

STRUCTURE OF THE REPORT

In Chapter Two, we explain the process we undertook to quantify the federal funding of hazard loss reduction R&D. In Chapter Three, we begin to characterize the results of our analysis, coming to conclusions about the allocation principles that underlie the hazard loss spending in the federal budget, including the types of research that receive the most funding and the nature of their contribution. Chapter Four considers the implications of our findings for policymakers and for future R&D strategies, including the obstacles preventing more-effective hazard loss reduction efforts. Finally, in Chapter Five, we step back to consider the larger picture of the expectations for R&D in a national hazard loss reduction strategy. A sample record from the RaDiUS database of R&D funding in the federal budget is reproduced in the Appendix.

Chapter Two

QUANTIFYING R&D FOR HAZARD LOSS REDUCTION

In this chapter, we describe our approach to quantifying federal spending allocated to R&D that contributes to the goal of hazard loss reduction. We outline the criteria used to identify R&D spending within the federal budget, and we describe the process we employed to isolate funding specifically devoted to hazard loss reduction.

First, let us clarify the terms. For our current purposes, we define natural hazards as natural processes that pose threats to humans, property, and the environment. Broadly, these include atmospheric processes, such as storms and hurricanes; geological phenomena, such as earthquakes and volcanoes; and a class of miscellaneous events, such as wildfires and landslides. In this setting, hazard loss *reduction* can thus take many forms, from the short-term (e.g., improvements in weather forecasting) to the long-term (e.g., changes in building codes or land use policy), from prediction-focused efforts to strategies designed to mitigate damage via sweeping infrastructure changes. For policy discussions, it is important to emphasize that R&D is a subset of these loss reduction activities. That is, an analysis of the R&D activities cannot be extrapolated to a comprehensive loss reduction strategy.

Our analysis necessitated using multiple data sources, as there is currently no single functionality to trace specific areas of R&D spending in a comprehensive way. In fact, there is no separately identified R&D budget within the federal budget. In turn, no means exist for the full range of agencies conducting hazard loss research to coordinate their spending with one another and to report on that spending en masse. Therefore, we developed criteria to search several sources in order to track all relevant R&D spending. Finally, upon isolating these expenditures, we were able to pinpoint the federal agencies conducting the largest amount of R&D and the kinds of hazards addressed by these efforts. In Chapter Three, we use these preliminary findings to develop a larger analysis of the federal hazard loss R&D efforts.

IDENTIFYING R&D FUNDS

In recent years, the United States has allocated more than $100 billion annually to R&D efforts in universities, in the private sector, and within the government itself.[1]

[1]In 2001, for example, the federal R&D investment was $90.9 billion, a 9.1 percent increase over the previous year's investment (Koizumi et al., 2000).

These funds are disbursed by more than 20 federal agencies, which allocate them to appropriate R&D endeavors conducted by government employees, private corporations, private individuals, educational institutions, and nonprofit organizations.[2] Seven of these federal agencies control 95 percent of the R&D funds: the Department of Defense (DoD), the Department of Health and Human Services (HHS), NASA, the Department of Energy (DOE), NSF, the Department of Agriculture (USDA), and the Department of Commerce (DOC).

Any analysis concerned with federal R&D funding confronts several classification issues. Questions inevitably emerge as to what actually constitutes R&D within each agency. Further, it is necessary to contend with the often murky distinction between R&D and science and technology (S&T) activities, as well as the differences among the research categories used in federal budgets. For our analysis of hazard loss reduction, further challenges arose from the cross-cutting policy environment, which complicates the process of mapping among budget expenditures, individual tasks, and policy goals.[3]

The Office of Management and Budget (OMB) provides the following definition of R&D: "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications" (OMB, 1996). Excluded are product testing, quality control, mapping, the collection of general-purpose statistics, experimental production, routine monitoring and evaluation of an operational program, and the training of scientific and technical personnel. This definition, moreover, is open to the interpretations of numerous individuals within a wide range of government agencies. OMB permits individual agencies a degree of liberty in determining which activities should be considered R&D, allowing each agency to use its own long-standing definition when reporting such activities to OMB.[4] As a result, for example, the activities that the Department of Interior (DOI) considers R&D may not be classified as such by NSF, whose definition of R&D appears more tightly tied to basic laboratory science (Fossum et al., 2000, p. xxix).

This variability recurs in the R&D subcategories within the federal budget. Specifically, R&D is broken down into three areas, or stages: basic research, applied research, and development. OMB defines each as follows:

- *Basic research.* Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications toward processes or products in mind.
- *Applied research.* Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.

---

[2]The exact number of agencies distributing funds varies from year to year. In 2001, the number was 24.

[3]In the analysis of R&D budgets, this problem is not unique to hazard loss reduction. Another notable example with important policy implications is the ongoing effort to quantify federal R&D budgets for studies of global climate change.

[4]For more details, see Wagner, 1998.

- *Development*. Systematic application of knowledge toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements.[5]

The criteria for R&D are thus broad, with an emphasis on the general purpose of the activity, i.e., increasing fundamental understanding, working toward a specific need, or developing a desired product. These criteria are so expansive that R&D ends up encompassing activities with a wide range of technical content and any institutional involvement. For example, the 2001 R&D budget included a dropout prevention project conducted in an Arapahoe, Wyoming, school district, as well as a DOE superconducting magnetic development project carried out by Livermore National Laboratory, which is operated by DOE and the University of California. These categories also incorporate efforts within parent programs that have widely varying policy goals, from the U.S. Postal Service's goals of improving processing equipment and developing and instituting innovative sorting and distribution techniques to DOE's energy conservation program, which has goals such as improving fuel economy and energy efficiency.

Such inclusiveness poses analytical challenges for gauging hazard loss reduction R&D, not only for the highly varied projects that are *included* but also for those that are *excluded*. Consider the case of the National Environmental Satellite Data and Information Service (NESDIS) within the National Oceanic and Atmospheric Administration (NOAA). NESDIS enjoys a large procurement budget (~$500 million), which is used to acquire and deploy a wide range of satellites. These instruments make a key contribution to NOAA's weather forecasting capability, but they also provide unique data streams that are essential for a range of R&D efforts. Because "procurement" is not included in R&D, these funds are not reflected in the R&D budget totals. Nonetheless, the funds make an important contribution to R&D, because they facilitate data streams that would otherwise be unavailable. This example illustrates the ambiguities of quantifying R&D expenditure: Even if one precisely defines the size of the R&D budgets and uses the accepted federal guidelines, the result may not be an accurate description of the total funds that contribute to R&D activities.

To complicate matters, in the civilian portion of the government, R&D is a subset of S&T, but in DoD, the reverse is true.[6] These definitional difficulties are compounded by the lack of a separately identified R&D budget within the larger federal budget. Most R&D spending is not even labeled as such and often falls under general program funding. Agencies receiving R&D funding of more than $10 million must submit data on their R&D each year, but this self-reporting again highlights different agency interpretations of R&D (NSF, 2002, p. 3).

---

[5]All definitions come from *OMB Circular A-11* (OMB, 1996).

[6]See Eiseman, Koizumi, and Fossum, 2002, for a discussion of the shifting classification of S&T in recent years, including the introduction of the FS&T (federal science and technology) budget category, which encompasses activities dedicated to creating new knowledge and technologies. FS&T includes both R&D and non-R&D programs.

Our challenge was thus to account for federal hazard loss reduction R&D spending by assembling and synchronizing several sources. We chose 2001 as our year of focus because it is the most recent year for which expenditure data are available in one of our primary data sources, the RaDiUS database (described below). Our first step was to identify programs focused on hazard phenomenology within science agencies, e.g., NSF, NOAA, NASA. Then we sought to isolate R&D from other activities within these programs.

We used three principal data sources:

- *RaDiUS*. This database, collected and maintained by RAND, details all R&D funding in the federal budget as determined from OMB computer records. The RaDiUS database is searchable via a web interface. At the time of our analysis, it contained data for FY 1993 to FY 2001. It allows users to search all ongoing R&D by agency, subject, location, the individuals or groups conducting the R&D, and budget function.
- *Office of the Federal Coordinator for Meteorology (OFCM).* OFCM coordinates the broad range of federal programs pertaining to meteorology. In each year since 1965, OFCM has issued federal plans setting out the provision of meteorological services and supporting research by agencies of the federal government. These annual reports outline weather-related program goals across 15 agencies and departments, including DOC, FEMA, NSF, and NASA. In these reports, OFCM distinguishes operational expenditures from R&D ("supporting research"). Illustrating the relative size of these efforts within a broader scope of hazard loss reduction, the FY 2003 report identifies $2.46 billion for operations and $384 million for supporting research.[7]
- *Federal budget submissions.* These documents, prepared by individual agencies, helped us in identifying research programs on natural hazards and in understanding their relationship to broader strategic goals within the federal government. Specifically, we looked at the submissions provided by NOAA, NSF, NASA, USDA, and DOI. The principal shortcoming of these documents is that they do not distinguish R&D funds from other funds, such as those for procurement and operations. Further, these submissions, by their very nature, reflect *desired* spending, not the actual expenditures appropriated by Congress.

All three sources made significant and needed contributions to our analysis as we examined R&D expenditures from a range of perspectives. As noted above, individual agency submissions were not sufficient in and of themselves, and OFCM covers only meteorological programs. As a result, RaDiUS proved an essential tool. Still, these other sources were necessary supplements to our RaDiUS findings, which are sensitive to the search terms and procedures used. The other documents provided an important cross-check to ensure that we identified all of the relevant programs. For example, the relevant weather-related DoD programs may not be readily identifiable through RaDiUS because the DoD budget is so large. In turn, OFCM budgets, unlike

[7]See OFCM's website at http://www.ofcm.gov.

RaDiUS, provide information about the *scale* of the operational programs. Finally, the OFCM budgets provide a useful perspective on the meteorological component of much larger programs, such as those in NASA. The agency budgets, in turn, help us understand the role of the R&D programs in the overall strategic goals of the agencies.

The perspectives with which we examined R&D funds are shown in Table 2.1. First, we identified all R&D spending. Then we focused on R&D dedicated to hazards, followed by the specific agencies conducting the hazard R&D. Next, we segregated the R&D funds based on the characteristics of the individual program goals.

Through this process, we developed a comprehensive listing of the federal programs engaged in R&D with relevance to reduction of hazard losses. These programs are distributed broadly across the government, ranging from the Federal Aviation Administration (FAA) to NSF to DoD. At the top level, these programs can be segregated into two categories: those explicitly focused on hazard loss reduction and those that include loss R&D as part of a larger mission. The programs that specifically and exclusively address hazard losses are the smaller group; they are presented in Table 2.2.

Table 2.1

Analytical Perspectives and Databases on Federal R&D Spending

Analytical Perspective for R&D Expenditures	Relevant Databases
Distributed across hazards	RaDiUS OFCM budgets
Distributed across different types of programs	RaDiUS Agency budgets OFCM budgets
Distributed across agencies	RaDiUS OFCM budgets
As a fraction of total federal outlays	RaDiUS

Table 2.2

Federal R&D Programs Focused on Hazard Loss Reduction

Agency/Program	Program Description and Goals
USGS: Geologic Hazards Survey	Geologic hazards surveys are conducted to study and predict earthquakes, volcanoes, landslides, and other geologic phenomena. Throughout U.S. history, geologic hazards have had adverse impacts on citizens and the economy. The program operates under the belief that losses from future phenomena can be significantly reduced through carefully planned studies of past and potential events and disaster-response planning. Studies in this subactivity are designed to contribute to the reduction of geologic hazard losses through a mixture of basic and applied research, preparedness, warning, and engineering. By reporting on the character of hazards and on the processes involved in their occurrence, the geologic hazards surveys provide information needed by federal, state, and local agencies to implement loss reduction strategies.

Table 2.2 (continued)

Agency/Program	Program Description and Goals
FAA: Aviation Weather Research Program	Hazardous weather is the leading cause of delays in the air transportation system and a major contributing factor to aviation accidents. System capacity is lost or inefficiently distributed when weather restrictions cannot be accurately predicted. R&D weather projects, several of which use the research of other federal agencies, are geared toward describing and predicting more accurately the location, extent, and movement of hazardous weather. These projects enable improved flight planning, reduce delays and diversions, and better enable ground crews to operate in hazardous weather. Enhanced oceanic weather forecasting, analysis of upper winds and temperature, and severe weather location improve flight planning and traffic management of routes, thus increasing the safety of the system. Timely and accurate weather information is critical to planning fuel-efficient and time-efficient flight plans, which directly support national energy conservation, environmental protection, and productivity goals.
DOI: Fire Research[a]	This research initiative is managed by a chartered research working team under the direction of the Interior Fire Coordination Committee. It includes projects necessary to improve fire-fighting methods and safety and to expand knowledge of the relationship among fire, the environment, and the various lands managed by the four participating agencies (the U.S. Fish and Wildlife Service, the Bureau of Land Management, the Bureau of Indian Affairs, and the National Park Service). The research initiative is not intended to fund general ecological research or research on long-term restoration of forest or range ecosystems. The DOI fire research priorities are coordinated with projects and priorities at Forest Service fire research laboratories.
NOAA: U.S. Weather Research Program	This program's efforts include applied atmospheric and hydrological research. Building on the basic research conducted by NOAA laboratories and the academic community, this program is focused on providing more timely and accurate weather and flood warning and forecast services to the U.S. public. Its meteorological research develops, tests, evaluates, and improves numerical models and analysis/forecast techniques used in weather and climate prediction, including techniques for predicting mesoscale phenomena (e.g., heavy precipitation, tornadoes, and severe thunderstorms). These forecasting techniques are developed and improved to use digital data from new observing systems, such as NEXRAD (Next Generation Weather Radar) and GOES-NEXT (geostationary satellites with higher resolution). Models are designed to improve hurricane tracking, hurricane probability estimates, and analyses. Also, storm surge models are developed to assist in hurricane evacuation plans for coastal basins. Hydrological research under this program works toward improved hydrologic and hydrometeorological models and procedures in support of the national flood forecasting and water resources forecasting programs, including improvements to the Extended Streamflow Prediction model and its complementary models in the National Weather Service River-Forecast System; specialized flood and flash-flood forecasting procedures using linked hydrological and meteorological models; and algorithms to combine NEXRAD precipitation estimates with data from satellites and other ground-based observation systems.

[a]USDA carries out a similar program on fire research that is coordinated with the DOI effort.

Each of the programs in Table 2.2 is funded as a separate line item within its parent agency, i.e., USGS, FAA, DOI, or NOAA. Thus, funding is easy to identify and track within the RaDiUS database.[8]

[8]From a budgetary perspective, these efforts should be distinguished from those of organizations such as NEHRP. NEHRP receives no direct appropriations from Congress; as such, its program goals do not appear in spending databases such as RaDiUS. Instead, four agencies—FEMA (the lead agency), NSF,

Programs explicitly focused on hazard loss are the minority of R&D efforts, however. A larger fraction of R&D relevant to hazard loss is carried out within larger programs with more expansive missions. For instance, the Earth Sciences Division of NSF funds field, laboratory, theoretical, and computational studies on the structure, composition, and history of the Earth, including R&D on earthquake effects and floods. Examples of these larger programs and their goals are summarized in Table 2.3.

A major complication for our analysis was the fact that for programs with broad goals, such as those in Table 2.3, there is no straightforward way to separate hazard loss R&D from other activities. This problem arises from two factors.

First, R&D funding tends to be allocated in a cross-cutting policy environment. That is, many programs contribute to multiple policy areas, making it difficult to allocate specific expenditures for unique policy goals.[9] Moreover, in the case of basic research programs, there is often an explicit de-emphasis on using R&D to achieve a priori policy goals other than broad technical or education/training agendas (see Popper, 1999). In this realm, we can identify R&D funds that contribute to hazard loss reduction goals, but, as we describe below, it is more difficult to identify funds that are allocated solely for hazard loss reduction R&D.

Table 2.3

Federal R&D Programs That Include Hazard Loss Reduction Elements

Agency/Program	Program Description and Goals
NASA: Earth Science Enterprise	The purpose of the Earth Science Enterprise is to understand the total Earth system and the effects of natural and human-induced changes on the global environment. The Enterprise aims to pioneer the new interdisciplinary field of research called “Earth system science,” which is based on the recognition that the Earth’s land surface, oceans, atmosphere, ice sheets, and biota are both dynamic and highly interactive. This research is yielding new knowledge and tools for weather forecasting, agriculture, water resource management, urban and land use planning, and other areas of economic and environmental importance. The Enterprise has established three broad goals: expanding scientific knowledge of the Earth system using NASA’s unique capabilities from the vantage points of space, aircraft, and in situ platforms; disseminating information about the Earth system; and enabling productive use of Earth Science Enterprise science and technology in the public and private sectors. The Enterprise evolved from the Mission to Planet Earth (MTPE), an integrated international program that uses satellites and other tools to study the Earth and its changing environment by observing the atmosphere, oceans, land, ice, and snow and their influence on climate and weather.

USGS, and NIST—apply a portion of their budgetary resources to their NEHRP program goals. These funds, which are reported on an irregular basis, are largely devoted to R&D within NSF, USGS, and, to a lesser extent, NIST. Because FEMA conducts no research, however, none of its NEHRP funding is dedicated to R&D.

[9]Consider, for instance, Murphy et al., 2000, which offers an evaluation of the federal antidrug budget through an examination of the widely varying budget methodologies of 10 government agencies.

Table 2.3 (continued)

Agency/Program	Program Description and Goals
NOAA: Office of Oceanic and Atmospheric Research	NOAA's oceanic and atmospheric research programs seek to provide knowledge and tools to improve NOAA services (weather warnings and forecasts, solar-terrestrial services, climate predictions, and marine services) and the understanding of environmental systems necessary for policy formulation (e.g., long-term climate change, acid rain, and ozone issues) and enhanced use of ocean resources (e.g., fisheries, water quality). One goal is the implementation of reliable seasonal and interannual climate forecasts to guide economic planning, e.g., to provide reliable one-year-lead-time forecasts of global climate variability, especially El Niño southern oscillation and the consequent precipitation and surface temperature distribution, that will enable the public to respond to forecasts, increase economic advantage, and mitigate economic losses and soil disruption.
NSF: Atmospheric Sciences	Research in the Atmospheric Sciences Division improves the understanding and prediction of weather, climate, and the solar-terrestrial system by expanding knowledge of the composition and dynamics of the Earth's atmosphere and geospace environment. More than one-third of its funding goes to the operation and maintenance of large, complex facilities required for research in the atmospheric and solar-terrestrial environment.
NSF: Civil and Mechanical Systems	The Division of Civil and Mechanical Systems (CMS) is dedicated to expanding knowledge of infrastructure construction, geotechnology, structures, dynamics and control, mechanics, materials, and the reduction of risks induced by earthquakes and other natural and technological hazards. The CMS Division also encourages cross-disciplinary partnerships to promote "leapfrog" discoveries using new technologies.
NSF: Ocean Sciences	The Ocean Sciences Division supports research to improve understanding of both coastal seas and deep ocean basins, including the sea floor and its organisms, and their relationship to human activities and environmental change. This division also offers opportunities for researchers to participate in ocean-related global change research programs and international field programs.
NSF: Earth Sciences	The Earth Sciences Division supports research in geology, geophysics, geochemistry, hydrology, and such related fields as tectonics, paleontology, and seismology. It funds field, laboratory, theoretical, and computational studies on the structure, composition, and history of the Earth and its processes. These studies are intended to provide the fundamental scientific basis for the discovery and use of mineral, energy, and water resources; for the prediction and mitigation of such natural hazards as earthquakes, volcanic eruptions, landslides, and floods; and for the environmentally sound use of the Earth by society.

Second, hazard loss R&D can occur as single projects within much larger research programs. For instance, research on the details of strong ground-shaking during an earthquake is performed in the same program as studies of the structure of the Earth's inner core. For the most part, this reflects the range of research topics within individual disciplinary areas. In other cases, hazard loss R&D is embedded in programs that may have another focus. The most important of these are the research programs focused on long-term global climate change. While the time scales for this work (e.g., decades to centuries) are beyond those of conventional hazard loss reduction activities, the research is focused on a comprehensive understanding of the global climate system, and the results can be applied to shorter-term predictions. Similarly, research is emerging in the global change community on the long-term trends of severe atmospheric events, and on whether these events are impacted by climate change. Understandably, the insurance community has shown interest in this work, indicating the strong connection to loss reduction efforts.

We thus faced serious challenges to a refined accounting of hazard loss R&D. We outline below the approach we fashioned to accommodate these intricacies.

ANALYSIS CRITERIA: ISOLATING HAZARD LOSS R&D

Our strategy for identifying the R&D expenditures pertinent to hazard loss required full consideration of the aforementioned overlaps and the varying importance of hazard loss policy goals within federal programs. For this effort, we developed a comprehensive methodology for distinguishing closely allied R&D efforts within the fields of seismology, atmospheric studies (chemistry, physics, dynamic meteorology), oceanography, and hydrology. For explicit loss reduction programs (see Table 2.2), we included all of the R&D expenditures. In broader R&D programs, especially those within NSF and NOAA (see Table 2.3), we had to account for overlaps that occurred when hazard R&D was conducted in the same program as R&D with other scientific or policy goals. Since these overlaps prevented us from conducting our study on the *program* level, we developed criteria to identify loss reduction R&D by examining expenditures at the *task* level within the RaDiUS database (see the Appendix). By examining these task descriptions on a case-by-case basis, we were able to identify R&D that expressly contributed to hazard loss reduction goals.

Our analysis was further facilitated by comparing the RaDiUS findings with the OFCM budget documents. As stated earlier, OFCM's annual summary provides descriptions of all weather-related research within individual programs across its 15 agencies, allowing us to distill specific hazard loss activities from other R&D activities. This feature was especially valuable for identifying weather-related research in large programs, such as NASA's Earth Science Enterprise.

For our examination of the RaDiUS results and the OCFM documents, we developed specific criteria for identifying hazard loss research within broader research programs by examining individual R&D task descriptions. We were primarily interested in identifying projects that contribute to the understanding of hazard phenomenology or of engineering solutions focused on the impacts of natural hazards. At the top level, we segregated these efforts into either earthquake or weather-related hazards. While there are hazards that fall outside of these two categories, they are largely addressed by hazard-specific programs (e.g., by the fire research program of DOI and USDA, or specific elements of the USGS hazard research program). The criteria for distinguishing among different types of R&D are discussed below.

Earthquakes

Earthquake R&D programs operate predominantly in USGS, NSF, and NIST as part of NEHRP, which was initiated in 1977. NEHRP receives formal budget authorization from Congress but no direct appropriations; as such, its program goals do not appear in spending databases such as RaDiUS. The NEHRP mission is to improve the understanding and characterization of earthquakes, improve model building codes and land use practices, reduce risks through post-earthquake investigations and education, develop and improve design and construction techniques, improve mitigation capacity, and accelerate application of research results. In addition, NEHRP handles routine earthquake monitoring and the notification of their occurrence and effects. These monitoring data can then be used in R&D, much as satellite data are used in weather programs. NEHRP funds are not specifically appropriated or identified within the President's budget; each of the agencies applies a portion of its budgetary resources to its NEHRP program goals. Because of the connection between NEHRP and earthquake research, there is a direct association between the allocation of these R&D funds and hazard loss reduction.

We included the entire USGS earthquake R&D program because it operates as part of NEHRP. Within NSF, earthquake studies are funded in two principal programs: as part of the CMS Division and as part of the Earth Sciences Division. Within the CMS Division, we identified projects pertaining to earthquake engineering at the task level. Within the Earth Sciences Division, we identified projects pertaining to earthquake effects, rupture mechanisms, and recurrence rates; we eliminated seismological studies pertaining to solid Earth geophysics. The latter studies utilize seismic energy only as a probe to study the structure of the Earth, not as the source of a natural hazard. A small component of seismic research also occurs in NASA's MTPE program.

Weather Hazards: Hurricanes, Floods, Tornadoes, Storms, and Drought

Loss reduction R&D for weather-related hazards is distributed across a wide range of programs and agencies. However, much of it occurs as R&D in support of operational weather forecasting programs and is thus quantified in OFCM's annual budget reports. We included these funds in our analysis for two reasons: First, there are strong intellectual connections across all types of weather forecasting (i.e., forecasting good weather requires data and analysis similar to those needed for forecasting hazardous weather); second, improved weather forecasts are viewed as a straightforward strategy for reducing hazard losses (e.g., by improved predictions of hurricane landfall).

Compared to earthquake R&D, research that contributes to the understanding of weather-related hazards is distributed over a large number of programs with only small (or nonexistent) "hazards" components (e.g., without programs equivalent to an NEHRP). More important, even the hazard programs in the area of weather emphasize a cross-disciplinary research approach that extends well beyond simple investigations of hazard phenomena. As an example, compare the text from the introductory web pages for two hazards programs related to earthquakes and hurricanes. The introductory web page for the USGS earthquake program reads:

> This web site is provided by the United States Geological Survey's Earthquake Hazard Program as part of our effort to reduce earthquake hazard in the United States. We are part of the USGS Geologic Division, and receive funding from the USGS Earthquake

> Hazards Program, which is funded, in turn, by the National Earthquake Hazards Reduction Program (NEHRP).[10]

That is, there is a direct correlation between the program structures and R&D for earthquake loss reduction. By comparison, the introductory web page for NOAA's premier hurricane laboratory reads:

> The Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami, Florida, specializes in basic and applied research in oceanography, tropical meteorology, atmospheric and oceanic chemistry, and acoustics. The principal focus of these investigations is to provide knowledge that may ultimately lead to improved prediction and forecasting of severe storms, better use and management of marine resources, better understanding of the factors affecting both climate and environmental quality, and improved ocean and weather services for the nation.
>
> AOML is NOAA's primary component for research on hurricanes. Research aims at improving the understanding and prediction of hurricane motion and intensity change. A key aspect of this work is the annual hurricane field program, supported by the NOAA Aircraft Operations Center research/reconnaissance aircraft. Research teams analyze data from field programs, develop numerical hurricane models, conduct theoretical studies of hurricanes, prepare storm surge atlases and windfield diagrams, and study interannual and decadal hurricane trends. Oceanographers at AOML provide and interpret oceanographic data and conduct research relevant to decadal climate change and coastal ecosystems. This research includes the dynamics of the ocean, its interaction with the atmosphere, and its role in climate and climate change. Additionally, AOML has an ongoing research program on the use of acoustics to measure coastal and deep ocean rainfall, an important element in calculating the global energy balance for climate monitoring and prediction.[11]

That is, the study of hurricanes requires a broad-based research program in oceanography, atmospheric sciences, and meteorology. Consistent with this approach, we include broad-ranging research activities to quantify the magnitude of the R&D that contributes to hazard loss reduction, regardless of current programmatic structures. This approach has important implications for interpreting our results. Specifically,

- Because of the scale and interactions in the global climate system, there is a huge range of research that can contribute to the understanding of weather-related hazards and thus can contribute to loss reduction. The challenge for our analysis was to place appropriate bounds on these topics for our expenditure analysis. With this in mind, we focused on atmospheric and oceanographic programs that contribute to weather forecasting and our understanding of hazard phenomenology. We did not extend the analysis further afield (e.g., to computer science focused on supercomputers that are used in weather simulations), because hazard loss reduction is only one of many research goals at this level (see below).
- Consistent with the programmatic structure, it is difficult to identify R&D activities that are explicitly hazard-related, except for work focused solely on such phenomena as hurricanes, tornadoes, or floods. The implication is that much of

[10]See http://earthquake.usgs.gov/about_us/.

[11]See http://www.oar.noaa.gov/atmosphere/atmos_aoml.html.

the R&D that contributes to the understanding of hazards also makes contributions to oceanography or atmospheric sciences. In this realm, our budget analysis quantifies the R&D that makes a direct contribution to the understanding of weather-related hazards. Because of the cross-cutting nature of the research, this quantity is larger than the quantity of R&D that exclusively targets hazard loss reduction (e.g., studies on tornado forecasting).

With these implications in mind, let us turn to our specific criteria. In the present environment, R&D on weather hazards occurs in USGS as part of its hazards and hydrologic programs; in NSF as part of its atmospheric and oceanographic research programs; and in NOAA as part of its Office of Oceanic and Atmospheric Research programs.

For the USGS programs, we included as contributing to hazard loss reduction all of the hydrologic line items found in RaDiUS,. For the NSF programs, we examined project descriptions at the task level to identify atmospheric and oceanographic research that contributes to hazard loss reduction. The following specific criteria were used for including or excluding projects:

Within NSF's *atmospheric* research programs, we

- Included projects pertaining to climate dynamics, large-scale dynamic meteorology, mesoscale dynamic meteorology, physical meteorology, and support for the National Center for Atmospheric Research (NCAR). Work in these areas provides the fundamental basis for the understanding of weather systems.
- Excluded projects pertaining to aeronomy, magnetospheric physics, paleoclimate, and solar-terrestrial physics. Research in these areas is largely outside the atmospheric processes that drive weather systems.
- Excluded R&D in atmospheric chemistry that focuses exclusively on air pollution, which is its own discrete problem, addressed in a separate policy sphere.
- Included projects on aerosols and the chemistry of the polar ozone hole. There is a growing recognition that aerosols play an important role in climate processes. In addition, the ozone hole can be viewed as a major natural hazard that needs to be mitigated.

Within NSF's *oceanic* research programs, we

- Included R&D that elucidates the connection between ocean and global climate processes. To this end, we examined research projects at the task level in the areas of international and special programs, ocean technology, and physical oceanography. Projects were eliminated if they focused on extremely long timescale processes, climate change, or the global carbon cycle.
- Excluded R&D in the areas of biological oceanography, marine geology, and ocean drilling.

For NOAA's Office of Oceanic and Atmospheric Research programs, we examined projects at the task level and applied the same criteria we used for the NSF programs.

We thus identified and included R&D funds associated with supercomputers for NCAR, aircraft services, and fleet maintenance, since they are important data-gathering facilities for hazard loss research that are unusual to find in R&D budgets. (Most such data gathering, as discussed earlier, is not considered R&D by OMB.)

Isolating NASA's R&D programs was more complicated. NASA funds significant levels of R&D that contribute to hazard loss reduction, largely within the Earth-science-focused MTPE program. In FY 2001, this program had R&D expenditures exceeding $1.4 billion, spread over a large hierarchy of programs. Program funds support university and corporate research and provide for a wide range of advanced remote-sensing instrumentation. Because of the scale of the effort and the nature of the research activities, it is difficult to associate individual tasks within this program with hazard loss reduction. For example, global positioning system (GPS) data play an important role in hazard R&D, but it would be inappropriate to put all of NASA's R&D funds for GPS in this category because these systems clearly have a much broader role in society. To address this problem, we used the R&D budget from OFCM to identify the meteorological component of NASA's R&D funds, and we associated these expenditures with hazard loss reduction R&D as outlined in Table 2.4.

Table 2.4

R&D Funding, by Agency and Hazard

Agency/Program	FY 2001 R&D ($ thousands)	Hazard Addressed by R&D								
		Flood	Hurricane	Tornado	Storm	Fire	Earthquake	Drought	Volcano	Other
DOC										
NIST										
Building and Fire Research Laboratory	22,517		x	x		x	x			
NOAA										
National Weather Service	23,054	x	x	x	x	x		x	x	
NESDIS	11,585	x	x	x	x	x		x		
Aircraft	9,393		x							
Fleet Maintenance	8,630		x		x			x		
Supercomputers	3,991	x	x	x	x	x		x		
Oceans and Atmospheric Research	207,892	x	x	x	x	x		x		
National Ocean Services	12,950	x	x		x			x		
NOAA Corps	7,423	x	x		x			x		
DOC Total	**307,435**									
NSF										
Oceans	70,747	x	x	x	x			x		
Atmospheric Sciences	183,847	x	x	x	x			x		
Earth Sciences: Hydrology	8,124	x	x		x					
Earth Sciences: Earthquakes	9,043						x			
Civil & Mechanical Systems: Wind	2,647		x	x						
Civil & Mechanical Systems: Earthquakes	20,775						x			
NSF Total	**295,183**									

Table 2.4 (continued)

Agency/Program	FY 2001 R&D ($ thousands)	Hazard Addressed by R&D: Flood	Hurricane	Tornado	Storm	Fire	Earthquake	Drought	Volcano	Other
NASA										
Mission to Planet Earth: Earthquakes	1,160						x		x	
Mission to Planet Earth: Meteorology	198,650	x	x	x	x	x		x		
NASA Total	**199,810**									
DOI										
Bureau of Land Management										
Fire Research	8,300					x				
Bureau of Reclamation										
Watershed Management	2,100	x								
USGS										
Hydrologic Sciences	45,752	x			x					
Earthquake Hazards	47,357						x		x	
Volcanoes	17,181								x	
Landslides	2,580									x
Geomagnetism	1,993									x
Coastal Hazards	18,330		x		x					
Biological Monitoring	100									x
DOI Total	**143,693**									
DoD										
Air Force	33,184	x	x		x					
Defense Meteorological Satellite Program	25,372	x	x		x					
Navy	18,706	x	x		x					
Army	13,243	x	x		x					
DoD Total	**90,505**									
USDA										
Fire Research	8,100					x				
OFCM Support	15,500	x			x					x
Soil and Water Sciences	2,150	x			x					x
Forest Service	4,550					x				
Cooperative Extension	602							x		
USDA Total	**30,902**									
DOT										
FAA Weather Program	30,341		x	x	x					
DOT Total	**30,341**									
EPA										
OFCM Support	6,600	x	x		x					
EPA Total	**6,600**									

Using this approach, we developed a comprehensive accounting of federal R&D spending on hazard loss reduction. Given the issues discussed above, our results are biased in the sense that they may overstate the U.S. government's overall commitment to hazard loss reduction R&D, as some of the activities address multiple goals. This is especially true for weather-related hazards, which constitute the largest fraction of the overall total.

To emphasize this point, we note that the quantitative details in Table 2.4 are quite sensitive to our criteria for identifying hazard loss R&D. This is especially problematic for weather-related hazards, which require analysis at the task level to distinguish R&D expenditures. Alternatively, if we had carried out the analysis relying only on program descriptions to identify hazard loss reduction efforts, our totals for weather-related hazards would have been significantly smaller.

As quantified in Table 2.5, expenditures for explicit weather-related hazard loss reduction programs are very small compared with the totals in Table 2.4.

This observation provides important context for interpreting the quantitative results in Table 2.4. Specifically, the difference between the findings in Table 2.4 and those in Table 2.5 indicates that R&D selection criteria play a critical role in budget analysis for hazard loss reduction. Different criteria would change the expenditures in Table 2.4, in some cases quite significantly, indicating that our quantitative results are somewhat subjective. That is, one can imagine a range of R&D budget levels for loss reduction; and each of the numbers is potentially valid, as long as the selection criteria are reasonable and justified. To this point, the peer review process for this report demonstrated that different analysts take different views on the R&D selection criteria, some more expansive and others more restrictive. This suggests a fundamental ambiguity for budget analysis on loss reduction, which has important policy implications, as discussed in Chapter Four.

The data in Table 2.4 identify FY 2001 expenditures on a program-by-program basis. To our knowledge, this is the first summary of these federal R&D expenditures; there is no evidence of interagency coordination for research activities spanning the full range of natural hazards.[12] As discussed in the following chapters, we believe that

Table 2.5

R&D Budget Levels for Weather-Related Hazard Loss Reduction Programs

Program	FY 2001 Funding ($ millions)
National Weather Service Operations and Research/Systems Acquisition	23,054
FAA Weather Program	30,341
NOAA National Severe Storms Laboratory	5,752
NOAA Atlantic Oceanographic and Meteorological Laboratory	8,930
Total	68,077

[12]At the Office of Science and Technology Policy (OSTP) level, federal efforts related to natural disasters are coordinated through the National Science and Technology Council (NSTC) interagency Subcommittee on Disaster Reduction (SDR). Dormant until recently, SDR has been reactivated; it was formerly called the Subcommittee on Natural Disaster Reduction.

this lack of coordination stems from fundamental ambiguities regarding a policy framework for comprehensive hazard R&D coordination.

With these caveats, we proceed to analyze our findings, de-emphasizing the specifics of our quantitative results. We looked at each program's R&D activities in terms of which particular hazards they addressed: floods, hurricanes, tornadoes, storms, fires, earthquakes, droughts, volcanoes, and "other," which covers such events as landslides. With this approach, we reached the following general conclusions about our quantitative results:

- Total R&D funding contributing to hazard loss reduction, according to our selection criteria, was approximately $1.1 billion in FY 2001.
- Almost 70 percent of the R&D funds were allocated to three agencies: NOAA, NSF, and NASA.
- Individual programs, especially weather-related programs, frequently address multiple hazards (e.g., floods and hurricanes).
- The largest fraction of the R&D funding supports weather-related hazard loss reduction—85 percent, according to the values in Table 2.4, which are sensitive to our R&D selection criteria.

In the following chapter, we extend our analysis in a logically consistent fashion to elaborate on the *qualitative* features of these initial observations, characterizing the hazard loss reduction portfolio—in particular, patterns in R&D allocation. As illustrated in Table 2.5, the analysis above quantifies the levels of R&D funding according to hazard types and by different federal agencies. To use these data in a policy framework, we need to extend the analysis one more step, characterizing the types of programs in which the funds are utilized. By this process, we develop a comprehensive picture of the way the U.S. government uses R&D funds to reduce the losses from natural hazards.

Chapter Three

CHARACTERIZING THE R&D EFFORT

In Chapter Two, we described our process for identifying the allocation of federal R&D dollars for hazard loss reduction activities. We found that at the most basic level, the largest R&D effort is devoted to weather-related hazards, with seismic hazards trailing well behind. In this chapter, we expand on these initial observations to develop a more comprehensive portrait of the federal prioritization of R&D that contributes to hazard loss reduction.

Because many types of R&D programs are supported by the federal government, it is useful to analyze the range of goals for hazard loss activities. This type of analysis provides information on the types of losses addressed by R&D, the balance between applied and basic research efforts, and the mechanisms for transitioning basic research to applications. With this information, one can begin to assess the payoffs from R&D investments and the effects of different R&D strategies.

We begin by constructing a framework characterizing the range of research programs. Using the data from Chapter Two, we map the R&D expenditures against the programs in this framework and identify the types of efforts that receive the largest share of funding.

TYPES OF R&D PROGRAMS THAT CONTRIBUTE TO HAZARD LOSS REDUCTION

To examine the goals and missions for the programs listed in Table 2.4, we divide the programs into three categories:

- *Hazard loss reduction programs.* These programs, shown in Table 2.2, focus solely on R&D that produces knowledge or technologies to diminish hazard losses.
- *Basic and applied research programs.* Housed largely within NSF, these programs are usually organized on a disciplinary basis, e.g., oceanography or structural engineering. Applied research programs (e.g., NSF's earthquake engineering efforts) often have a direct link between R&D and hazard loss reduction. However, in basic research programs, the link can be indirect. For example, research that improves knowledge of ocean processes can enhance understanding of hurri-

cane formation, which may improve hurricane forecasting, which may in turn result in mitigation or at least short-term lifesaving evacuation.

- *Operational support programs.* These programs carry out R&D to support and improve existing operational programs. The foremost examples occur in the U.S. Weather Research Program, which includes activities designed to improve regional mesoscale models, the central tools for the operational forecasting of local weather systems, and in DoD R&D activities in support of military meteorological programs, such as data-collection improvements in its Defense Meteorological Satellite Program.

We use these classifications because these top-level qualities inevitably influence the nature of research programs' contributions. Clearly, the most direct contributions come from the hazard loss reduction programs, where the R&D is focused on technologies and information to lessen property damage and loss of life. In these types of programs, there is a strong expectation that basic research results will be transitioned into practical applications. While this approach is advantageous for meeting policy goals, it can produce a difficult working environment for those engaged in R&D from which a rapid "payoff" is expected.[1]

By comparison, the goals for basic and applied research programs are often quite broad, and thus immediate contributions to hazard loss reduction are not necessarily planned or anticipated. From a policy perspective, these types of programs illustrate the long-standing difficulty of anticipating the benefits of R&D.[2] On the one hand, metrics for such programs will always be elusive. On the other hand, the potential payoffs can be great because a broad range of research areas is typically under consideration.

Finally, we note that the hazard loss contributions of operational support programs can be indirect. Here, R&D activities generally focus on strengthening operational efforts (e.g., efforts to predict specific hazards). As a result, loss reduction efforts are a secondary goal. In cases where R&D is focused on the technological details of the operational program (e.g., improved software for faster data analysis), the contributions to loss reduction may be oblique and thus hard to measure. Consider, for example, a program such as NOAA's Weather Radio Network (NWR). NOAA may submit a budget request to improve its NWR transmitters for broadcasting warning and forecast messages to the public. These improved transmitters then may enhance warning capabilities and eventually lead to severe-weather loss reductions, due, for instance, to citizens reacting to warnings by staying off the roads. But, as this example shows, the contribution to loss reduction follows a winding path and is difficult to track.

---

[1]Such expectations underlay criticism by the Office of Technology Assessment (OTA) of NEHRP. In its 1995 report *Reducing Earthquake Losses*, OTA charged NEHRP with failing to focus on implementation of research results. In contrast, economic analyses of basic R&D efforts have demonstrated that the time scales for reaping benefits from new applications can be quite long. For a survey of various means to quantify basic research, see Popper, 1999.

[2]See Popper, 1999.

Funding Distribution by Program Type

Within this framework, our next step was to assess the distribution of R&D funding across these three program types. Our findings are shown in Table 3.1

Table 3.1

R&D Funding, by Program Type

Agency	Program	FY 2001 R&D ($ thousands)
	Hazard Loss Reduction Programs	
DOC/NIST	Building and Fire Research Laboratory	22,517
DOI/Bureau of Land Management	Fire Research	8,300
DOI/USGS	Earthquake Hazards	47,357
DOI/USGS	Volcanoes	17,181
DOI/USGS	Landslides	2,580
DOI/USGS	Geomagnetism	1,993
DOI/USGS	Coastal Hazards	18,330
DOI/USGS	Biological Monitoring	100
USDA	Fire Research	8,100
Total		**126,458**
	Basic and Applied Research Programs	
DOC/NOAA	Fleet Maintenance	8,630
DOC/NOAA	Supercomputers	3,991
DOC/NOAA	Oceans and Atmospheric Research	163,437
DOI/USGS	Hydrologic Sciences	45,752
USDA	Soil and Water Sciences	2,150
USDA	Forest Service	4,550
USDA	Cooperative Extension	602
NSF	Oceans	70,747
NSF	Atmospheric Sciences	183,847
NSF	Earth Sciences: Hydrology	8,124
NSF	Earth Sciences: Earthquakes	9,043
NSF	Civil and Mechanical Systems: Wind	2,647
NSF	Civil and Mechanical Systems: Earthquakes	20,775
NASA	Mission to Planet Earth: Earthquakes	1,160
NASA	Mission to Planet Earth: Meteorology	133,500
Total		**658,955**
	Operational Support Programs	
DOC/NOAA	National Weather Service	23,054
DOC/NOAA	NESDIS	11,585
DOC/NOAA	Aircraft	9,393
DOT/FAA	Weather Program	30,341
DoD	Air Force	33,184
DoD	Defense Meteorological Satellite Program	25,372
DoD	Navy	18,706
DoD	Army	13,243
USDA	OFCM Support	15,500
EPA	OFCM Support	6,600
NASA	Mission to Planet Earth: Meteorology	67,400
DOC/NOAA	National Ocean Services	12,950
DOC/NOAA	NOAA Corps	7,423
DOC/NOAA	Oceans and Atmospheric Research	44,455
Total		**319,206**

Funding was determined for these categories based on the following criteria:

- Hazard loss reduction programs were identified, and all funds were included for that category of programs.
- All NSF funds were included in the basic and applied research category.
- The operational support budgets largely reflect the R&D totals from OFCM, except for the NASA budget, which was examined at the task level to differentiate R&D for operational weather forecasting from basic R&D on climate systems.
- Within the NOAA Oceans and Atmospheric Research Program, the R&D funds identified by OFCM were included in the operational support category. The remaining funds associated with hazard loss reduction (see Table 2.4) were included in the basic and applied research category.

Breaking down R&D into these three program types led us to the following observations:

- The largest share of spending occurs in basic and applied R&D programs of NSF, NOAA, and NASA. The largest share of this work occurs in climate-related programs (e.g., NOAA's Oceans and Atmospheric Research, NSF's Atmospheric Sciences, NSF's Oceans, and NASA's MTPE). These efforts support policy goals related to global climate change as well as to hazard loss reduction.
- The second largest category is operational support programs, which focus almost exclusively on meteorology and weather forecasting and are on relatively short time scales. In general, the operational efforts address individual weather events (e.g., storms, hurricanes, tornadoes, floods) that are predicted to occur within minutes or days or weeks. The longest time scales they consider are interseasonal (e.g., for El Niño forecasts).
- Explicit loss reduction programs receive the least R&D funding, only $126.5 million in FY 2001. USGS is the largest contributor to these efforts.

Assessing Program Impact

To illustrate the effects of different programmatic approaches to R&D, we present a range of loss reduction strategies and the possible contributions of R&D results. We structure the discussion on the following top-level view of R&D and hazard loss reduction: The primary role for R&D is to provide new or improved information or technologies that can reduce the impacts of natural hazards. In this framework, ways that R&D contributes to loss reduction include the following:

- More-accurate weather forecasts.
- Improved characterization of earthquake ground-shaking.
- Improved understanding of hazard-resilient structures.
- Improved capabilities for modeling flood behavior.

In all of these cases, R&D contributes to loss reduction by improving the understanding of hazard phenomenology. That is, R&D improves understanding of the full range of processes that lead to natural hazards. In turn, this leads to a predictive understanding that can be used to develop mitigation strategies. At the coarsest level, such strategies might consist of evacuation plans to avoid an advancing hurricane. At increasing levels of sophistication, they could involve detailed engineering to improve the strength of critical infrastructure (bridges, buildings, communications towers, etc.).

With this perspective, we summarize a broad range of loss reduction strategies and supporting R&D in Table 3.2. The results are drawn from our analysis of hazard loss reduction efforts carried out at all levels of government, by private corporations, and by individual property owners. The most important conclusion from this analysis is that time scales play the central role in differentiating loss reduction efforts. When only short times are available, only limited actions are feasible and the associated levels of loss reduction are relatively small. At short time scales, the most important loss reduction strategies focus on evacuations and saving human lives. At longer time scales, loss reduction efforts can focus on more comprehensive strategies to improve the resilience of communities and infrastructure.

Table 3.2

Time Scales for Loss Reduction Strategies

Time Scale	Loss Reduction Strategy/Natural Hazards	Affected Losses	Types of Supporting R&D
Minutes	Rapid evacuation/shelter Tornadoes Flash floods Advancing wildfire Tsunamis	Reduced loss of life	Improved weather forecasts; real time seismic warning systems
24–72 hours	Evacuation of people and valuables Floods Hurricanes Fortifying structures Floods Hurricanes Winter storms Strengthening defenses Floods	Reduced loss of life; partially reduced losses for some structures.	Improved weather forecasts
Weeks	Develop contingency plans Wildfires Droughts	Reduced economic losses if action is taken	Improved weather forecasts
6 months	Develop interseasonal contingency plans Hurricanes Drought	Reduced economic losses if preparedness is improved.	Improved weather forecasts
1 year	Retrofit existing structures Earthquakes (minimum time scale) Hurricanes Winter storms Tornadoes	Substantial loss reduction for retrofitted structures.	Structural engineering; R&D on hazard phenomenology

Table 3.2 (continued)

Time Scale	Loss Reduction Strategy/Natural Hazards	Affected Losses	Types of Supporting R&D
5–10 years	Retrofit existing structures Earthquakes Rebuild existing structures Earthquakes Hurricanes Relocate structures Floods Flash floods Implement nonstructural flood-control measures Floods Implement land use policies to reduce vulnerability Floods Hurricanes Earthquakes Wildfires Flash floods	Substantial avoidance of infrastructure losses; reduced loss of life	Structural engineering; R&D on hazard phenomenology

For our analysis, time scales provide a simple methodology for characterizing the outcomes of different R&D efforts. Specifically, in terms of the magnitude of avoided losses, R&D that facilitates short-term loss reduction activities has a more limited impact than does R&D that supports longer-term activities. Short-time-scale R&D includes almost all research aimed at improving weather forecasting capabilities. R&D focused on longer-term responses includes structural engineering and its supporting scientific research (e.g., wind engineering together with measurements/modeling of the wind fields during a tornado).

These results have important policy implications for R&D expenditures and program goals. Specifically, they suggest that operational support R&D will make only a limited contribution to hazard loss reduction because it focuses on information products delivered on relatively short time scales. By comparison, R&D in hazard loss reduction programs would seem to have greater potential because those programs focus on the phenomenology of natural hazards, which can be applied to longer-term engineering solutions. Finally, the impact of the basic and applied research programs is mixed, depending on the details of the research efforts (i.e., whether they support long- or short-term response efforts).

OVERALL ASSESSMENTS

Consideration of the programmatic structure for hazard R&D and the research needs for loss reduction strategies leads to the following observations:

- The fact that the majority of the R&D funds (approximately 70 percent) are allocated to basic and applied and operational support research programs emphasizes the cross-cutting nature of the policy environment. That is, most of the research expenditures that support hazard loss reduction activities also contribute to other policy goals. This cross-cutting leads to decisionmaking challenges for allocating R&D funds or determining overall funding levels.

- The greatest loss reduction is achieved by mitigation actions, which require long time scales to implement and are largely directed at infrastructure vulnerability. This observation suggests a need for a new metric for prioritizing R&D activities.

Given these findings, we now turn to the difficulties confronting policymakers responsible for making spending choices and setting priorities in this environment. They must weigh such issues as returns on investment, the spread of funding across hazards, and the time span and payoff of various R&D efforts. The question is whether the tools decisionmakers need—accurate loss data, reliable and consistent techniques for comparing hazard losses, and a means by which to determine the benefits and costs of various R&D efforts and mitigation measures—are in fact available.

Chapter Four

THE POLICY CHALLENGE FOR HAZARD LOSS R&D

The findings outlined in the previous chapters raise a number of difficult policy questions for the prioritization of federal funding for R&D on hazard loss reduction. Would different R&D strategies lead to improved loss reduction? Are the standards or principles implicit in the present R&D allocation strategy the most beneficial ones? Should the spread be balanced, or should the bulk of funding be applied to the activities promising the greatest return on investment? Or is the goal to have as diverse a portfolio as possible? Indeed, in the face of rising hazard losses in recent years, will the present R&D portfolio meet the challenge, or must policymakers take action now to reevaluate R&D investment in lessening hazard losses?

All of these key policy questions hinge on data that can elucidate the relative benefits of a specific kind of R&D for a specific hazard type. A comprehensive evaluation of the present federal allocation strategy requires a means by which to assess the "payoff" of hazard loss R&D efforts and thereby determine whether the investments are worth the associated costs. Unfortunately, the most immediate problem for policymakers is the inability to determine these values. In this chapter, we discuss a range of factors that contribute to this problem.

THE MISSING METRIC

Substantive assessments of national hazard loss R&D efforts are severely constrained by the lack of accurate loss data—the primary information that might be used to measure the effectiveness of such efforts. The federal government has no uniform procedure in place for compiling figures on the economic effects of natural hazards. Insurance companies provide useful data on their payouts following a disaster, but data on uninsured losses are particularly difficult to gather. And the insured losses are only a fraction of the total losses. For example, private insurers in the United States do not offer coverage for flood losses. More broadly, there is no thorough, standardized database that pulls all the pertinent information together in a way that can be easily accessed and used by policymakers, government agencies, localities, nonprofit organizations, and other interested parties.

With no governmentwide framework for loss calculation or even definition, the relevant federal agencies provide their own damage estimates.[1] One agency, NOAA's National Weather Service, gathers severe-weather damage estimates reported by each state and distributes them in its monthly publication *Storm Data*. The quality of the data varies widely, depending on the state and its gathering procedures. Moreover, until 1996, property and crop damages were provided only in terms of a range, e.g., $5,000 to $50,000. These data ranges and the inconsistent gathering techniques obviously make it difficult to aggregate losses and provide total loss estimates from multiple hazards or years with any degree of confidence. For example, *Storm Data* figures show the losses from flooding from 1975 to 1994 as between $19.6 and $196 billion in 1994 dollars (H. John Heinz III Center for Science, Economics, and the Environment, 2000, p. 56).

In addition to this lack of standardization and the general unwieldiness of available data, any determination of the cost-effectiveness of various strategies is perpetually hampered by a number of inherent problems that make it difficult to collect information following a disaster:

Losses may be indirect. Direct losses, such as physical destruction to individuals and property, are generally evident and quantifiable, but indirect losses may be far less so. In its proposed framework for estimating disaster losses, a FEMA-sponsored NRC study classifies as indirect any losses of income or production that result from a disaster, such as losses in "sales, wages, profits due to loss of function, slowdowns or shutdowns induced by demand reduction from damaged firms, spending reductions from income closes triggered by firm closures to cutbacks" (NRC, 1999, p. 37). Likewise, the H. John Heinz Center cites collateral losses such as the failure or migration of small businesses, reduced property values, the decline of tourism revenue, higher insurance rates, or even a lack of insurance availability. That study also highlights the indirect losses stemming from long-term effects on nature, such as the loss of habitats, erosion-buffering beaches, and wetlands. Finally, and perhaps even more difficult to measure, are the psychological consequences for affected individuals (H. John Heinz Center, 2000, p. 49).

Losses are spread over time. It can take months or years to collect all loss data associated with a given event. While the initial losses—collapsed buildings, shattered bridges, broken water mains—are often quantifiable, other costs, including many of the indirect costs outlined above, are not generated until well after a disaster. In turn, basic physical property damage is not always immediately apparent, e.g., earthquakes can incur structural harm that may not be visible to property owners for several months. As such, early loss figures may vastly underestimate actual losses.[2]

---

[1]Indeed, even the terminology can be slippery. The National Research Council (NRC), for instance, clearly delineates between *losses, costs,* and *impacts*, with *costs* referring to direct payouts, *losses* referring to negative economic impacts, both direct and indirect, and *impacts* (the broadest term) encompassing market-based impacts as well as nonmarket effects such as environmental and psychological consequences (NRC, 1999).

[2]For a full analysis of the difficulties of natural hazard loss estimation, see NRC, 1999.

Losses to some are gains to others. Collecting loss data is further complicated by the fact that losses for some parties become opportunities for others. The most obvious beneficiaries of many hazards are construction companies. If a roof is torn from a building during a hurricane, the local roofing contractor who builds the new one gains from the property owner's loss. The question thus becomes, What are the most appropriate means to factor any gains against associated losses? At present, these determinations are made via different means across different organizations or agencies, with no uniform method in place.

The Heinz and NRC studies both offer frameworks by which to overcome such impediments to the retrieval of full and accurate loss data. The NRC report outlines a detailed strategy for data-collection efforts, recommending, for instance, that DOC should be responsible for compiling the national loss database and that OMB should develop yearly estimates of disaster loss payouts. In 2000, William H. Hooke, past chair of the Subcommittee on Natural Disaster Reduction (SNDR), which has since been renamed the Subcommittee on Disaster Reduction (SDR)), highlighted the NRC study's call for standard loss data methodologies in a statement before the Congressional Natural Hazards Caucus. Hooke lamented the lack of federal agency response to its recommendations and emphasized, "Our national experience shows we do well in those areas where we do track progress—e.g., inflation, economic growth, crime rate, etc. Congress should foster such activity." Thus far, however, these recommendations have not been put into practice.

As discussed in Chapter Two, there is no coordinated federal R&D budget for hazard losses, and allocation decisions are highly decentralized, occurring within numerous agencies. Efforts to coordinate R&D activities in specific areas perpetually meet organizational obstacles, and hazard loss R&D is no exception. SNDR was set up to facilitate interagency cooperation and coordination in natural hazard assessment, mitigation, and warning, but its work was greatly hindered by the lack of metrics that could facilitate an overarching R&D strategy based on the most productive distribution of funding. With no means to measure the value of various hazard loss R&D efforts, SDR and relevant federal agencies are hamstrung. Accurate loss data are invaluable for prioritizing R&D activities and evaluating mitigation efforts. Calculating the losses from building damage following an earthquake, for example, can demonstrate the economic value of investing in seismic engineering R&D to improve infrastructure sustainability. Data are also essential for prognosticating future losses, providing information that can help localities determine budget allotments and prepare contingency plans.

Further, the Heinz and NRC studies both stress the need for a baseline set of loss data to use in detailed *loss modeling*. Loss modeling simulates the consequences of potential disasters and thus provides a key means for reducing hazard losses. Specifically, loss modeling uses statistical models to describe a range of possible damage states in response to hazard events with a defined probability of occurrence. Significant uncertainties could be addressed through R&D and focused data collection following disasters. For example, R&D and loss data could contribute to model descriptions of the damage to infrastructure and buildings resulting from a natural hazard and the assessment of probabilities of future hazards.

While loss modeling is largely carried out with proprietary software by the insurance industry, important steps have been taken to create publicly available codes that are amenable to R&D input. In 1997, FEMA and NEHRP, along with the National Institute of Building Safety, inaugurated a standardized methodology for estimating earthquake losses called Hazards U.S., or HAZUS®. HAZUS uses geographic information system (GIS) software and algorithms to calculate earthquake loss data, including ground-shaking, damages to buildings and transportation systems, casualty numbers, numbers of displaced people, and total estimated economic losses. Efforts are now well under way to extend HAZUS's capabilities to make it a multihazard tool, with new modules for estimating flood and hurricane losses expected during 2003. HAZUS also could prove a vital supplement to any large-scale effort to formulate a federal compendium of loss data. The 1999 NRC study, for instance, proposes the use of HAZUS—and the extension of its capabilities to hazards other than earthquakes—in the creation of its recommended comprehensive national loss database. The data supplied by state and local governments using HAZUS could help build that database. The NRC report also suggests that HAZUS and other loss estimation tools could be used to establish standardized dollar thresholds to determine which events should qualify for inclusion in the database.[3]

The insurance industry has also made major advancements in the use of loss modeling in recent years. After the catastrophic losses of events such as Hurricane Andrew, the industry determined that it needed to increase its use of modeling. Its subsequent efforts have frequently assisted in the development of new building codes mandating more hazard resistance, suggesting additional uses for loss modeling. Loss modeling has obvious utility in demonstrating the costs of hazard losses and the consequent need for—and value of—hazard loss reduction R&D. Its potential for improving mitigation efforts, however, is also highly significant. Simulation models can illustrate how hazards operate—the time frames, the effects of various factors and probabilities, the range of impacts—and thus can help identify promising means by which to lessen losses, sustain structures, and facilitate emergency response. Finally, in the absence of a comprehensive loss database, loss modeling functions as a stand-in, particularly for aggregating indirect losses.[4]

In the absence of reliable sources of data on hazard losses, the current understanding of hazard outcomes has been derived from a range of sources with widely varying analytic techniques. The results of this work are thus presented as estimates rather than measurements of hazard losses. At their level of detail, the estimates cannot be used to assess the effectiveness of different R&D strategies. However, they do pro-

---

[3]Models used by insurance and reinsurance companies or state agencies include EQECAT's USWIND, a hurricane simulation model, and USQUAKE, an earthquake model; Applied Insurance Research's Catastrophe Modeling, which simulates natural hazards and projects their effects on property, and its new Advanced Component Method, which assesses building vulnerability to earthquakes; and The Arbiter of Storms (TAOS), a meteorological hazard model developed by Watson Technical Consulting.

[4]As the NRC study notes, "Due to the limited sources of indirect loss data, statistical models are often used to compile indirect loss estimates. Though these models may help address problems due to a lack of available data, they must become more reliable if they are to be used as guides in setting mitigation and other hazard-related policies. If this is to occur, however, accurate, firsthand (primary) data on indirect losses must be available for model calibration and validation" (NRC, 1999, p. 47).

vide a top-level description of loss magnitudes and the variation among different types of hazards.

Any attempt to estimate hazard losses with the available data faces three principal challenges. First, because natural hazards occur at variable times with variable magnitudes, data collected in any single year, or even over multiple years, will certainly be skewed because they will not reflect the long-term probabilities of hazard events. This is especially problematic for hazards with long recurrence times, such as earthquakes. To address this problem, loss estimates are presented on an "annualized" basis, reflecting the average annual losses in response to the expected distribution of hazard events. Second, society's vulnerability to hazards has been changing with time, so loss data from historical events are of limited utility. For example, hurricane loss data from the 1950s have limited application to the present because of the dramatic changes in the level of coastal development. Addressing this problem motivates the third challenge for hazard loss estimates—the lack of accurate scaling relations to characterize structural damage from hazards of different magnitudes. While the need is straightforward, it is difficult to address because of the complexity of the built environment in urban settings and the nonlinear nature of hazard impacts. Specifically, hazard losses often result from the interactions between different infrastructure elements (e.g., natural gas lines and buildings), and differences in losses between hazard events are usually much greater than the proportional change in hazard intensity.

Table 4.1 summarizes annualized hazard loss estimates obtained from a range of sources for different hazard types. The most important conclusions from these estimates are the following:

- The three hazards that result in the greatest losses are hurricanes, earthquakes, and floods.

Table 4.1

Estimated Annualized Losses, by Hazard[5]

Hazard	Estimated Annualized Loss ($ billions)
Floods	3.0
Hurricanes	5.0
Winter storms	0.3
Tornadoes	1.0
Hail	0.7
Extreme heat	0.1
Extreme cold	0.5
Total, all weather	**10.6**
Wildfires	2.0
Earthquakes	4.4

[5]See Pielke and Carbone, 2002, for a discussion of weather-related losses. These values are comparable except for flood losses, where we use the average loss from 1903–1999, as compiled by the National Weather Service. The earthquake losses are derived from HAZUS loss simulations for the entire United States using updated earthquake probabilities from USGS (see FEMA, 2001). Wildfire losses are estimated from recent federal fire-fighting expenditures for wildfires.

- Taken together, the losses from weather-related hazards are more than twice the estimated losses from earthquakes.
- If wildfire losses are included with the weather losses, the difference between weather and earthquake losses is almost a factor of three.

We next compare the estimates in Table 4.1 with the expenditures in Table 2.4, which lists R&D funding by hazard, in order to assess the allocation of R&D funds on a loss-proportional basis. Specifically, the data in Chapter Two show that the difference in funding between weather- and earthquake-related R&D (exclusive of wildfires) is more than an order of magnitude. Yet the difference in the losses between the hazards is only a factor of two to three. On this basis, we conclude that hazard-related weather R&D is large compared to earthquake R&D on a loss-proportional basis. In part, this may reflects society's willingness to pay for improvements in short-term prediction of weather events, particularly because weather predictions, while expensive, have a well-defined economic value, and they can save human lives. That is, society may perceive a greater marginal value to weather-related R&D, leading to a large allocation of resources to these efforts. It may also reflect the cross-cutting nature of R&D budget decisions, which biases our analysis toward an overstatement of the government's commitment to hazard loss R&D. If it were possible to eliminate the bias, the discrepancy between earthquake- and weather-related R&D might be reduced.

THE HUMAN FACTOR

The present difficulties in determining hazard loss are not only technical and quantitative, they are behavioral as well. Loss reduction is largely viewed as a question of human behavior—in particular, the willingness of humans to take actions or incur expenses to reduce their vulnerability to natural hazards. Many hazard losses are in fact avoidable, the result of individual choices (e.g., choosing to live, work, or develop in a high-risk area) or communitywide failures to take steps to protect lives and property. Insurance industry estimates point to lax compliance with building codes as the culprit for between 25 and 40 percent (between $4 billion and $6.5 billion) of the insured losses generated by Hurricane Andrew in 1992 (Pielke, 1996).

Further, hazard losses could be substantially reduced if humans did not choose to live in coastal regions that are vulnerable to flooding and hurricanes, if they did not build on floodplains or in remote areas susceptible to wildfire, if they did not relocate to seismically active regions, and so on. Focusing on human culpability harkens back to the classic Gilbert White hypothesis that disaster losses are created by society's decisions. While working in the Roosevelt administration in the 1930s, White came to believe that many natural disasters, from floods to the Depression-era Dust Bowl, stemmed from human choices. Often called the "father of floodplain management," White argued that rather than concentrating on relief to flood victims, the government could solve the problems of flood damage through environmentally sound land use planning. In his influential 1945 study *Human Adjustment to Floods*, White argued that the government should encourage its citizens to adapt to the floodplain environment and minimize the harmful effects of floods either by restricting development or by making more productive use of floodplains based on a full understanding of their environmental purpose.

Given the mass migration of humans to coastal regions in recent years, the question of human responsibility in hazard losses is perhaps even more relevant today than it was when White first put forth his theory. In this light, questions naturally arise about the value of R&D as a loss reduction strategy compared to the more immediate and certain payoffs of reducing society's known vulnerabilities.

This issue may explain in large part the overemphasis on weather prediction R&D. The human factor probably plays a forceful role in this imbalance. After all, it is not surprising that individuals tend to be more likely to respond to, say, an urgent warning of a developing forest fire than to a recommendation that those living in vulnerable areas thin out vegetation around their homes, cover vents with mesh, enclose their balconies and eaves, treat their siding with fire-retardant chemicals, and cover their chimneys with spark arresters.

The human factor poses challenges for policymakers confronting choices about R&D funding. Should R&D funding correlate with human vulnerability to hazards—that is, the hazards that affect the greatest number of at-risk individuals? Should R&D allotment cater to the kinds of measures humans are most likely to adopt (e.g., measures related to evacuation)? Although the loss reduction benefits of such mitigation measures may be greater, is the investment worthwhile if citizens or communities will not implement them? That is, in addition to these quantitative (data limits) and qualitative (human behavior) obstacles, hazard loss reduction R&D faces the challenge of what has been termed the "implementation gap."

THE IMPLEMENTATION GAP

Some have argued that priorities for loss reduction should emphasize available knowledge rather than future R&D. This view is based on the so-called implementation gap, the difference between loss reduction measures that are feasible and the actions that are performed in practice. OTA emphasized this gap in its 1995 analysis of NEHRP. It praised the program's advances in earthquake science but concluded that its efforts at reducing risk "lag far behind the knowledge base created by [its] research" (U.S. Congress, OTA, 1995, p. ix). The authors argued that implementation of existing knowledge is the "chief bottleneck hindering seismic mitigation efforts," asserting that earth sciences and engineering research has already provided much of what is needed to prepare for earthquakes: "[W]e have a good idea of where earthquakes can occur (at least for the more seismically active areas); we have a sense of their potential severity and probable effects; and where we choose to prepare, we can significantly reduce the likelihood of massive destruction and loss of life. The problem is that we do not always choose to prepare" (U.S. Congress, OTA, 1995, p. 96).

Such a position, however well founded, may serve to buttress arguments for federal cuts in R&D rather than to spur implementation; after all, implementing the findings of past R&D does not obviate the need for future R&D. The so-called implementation gap, however, demonstrates the extent to which R&D is still contingent on human behavior, i.e., the willingness of people to receive knowledge and act upon it. As much as R&D concludes that overdevelopment of land greatly increases treacherous runoff from heavy rainfall, the transformation of that finding into zoning, ordinances, and community planning efforts requires changes in human behavior and perhaps in the national philosophy of progress and expansion.

Still, changes can occur. State and local programs have made great advances with initiatives such as carrying out seismic-resistant upgrades to structures and bridges, improving building codes, disseminating wind shutters, and clearing floodplains. In the years following Hurricane Andrew, Florida's state and county governments began a long process of mitigation measures, resulting in many of the strictest building codes in the country. A study commissioned by the Institute for Business and Home Safety concluded that if all buildings in south Florida met the current stringent Miami-Dade and Broward county code requirements, a repeat of Hurricane Andrew in 2002 would have resulted in about $8.1 billion less damage to homes and $2.3 billion less damage to businesses than occurred in 1992. In addition, FEMA's hazard mitigation programs have made many relief funds and grants contingent on compliance with land use policies and development restrictions. Of course, these mitigation efforts derive from both past and current hazard R&D and depend on future R&D for help in determining the most effective, resistant, resilient, and life-saving measures. Moreover, without an ongoing investment in R&D, the knowledge base remains static and cannot reflect the rapidly changing environmental conditions and societal trends that have such an influence on the economic costs of hazards.

The problem of encouraging implementation of R&D findings probably stems from entrenched views of basic research as remote from "real world" applicability. While this is certainly the case for some fields (e.g., high-energy physics), there are many examples in which basic research makes a direct contribution to a practical application (see the discussion of Pasteur's Quadrant below). For the policy process, it is crucial to marshal evidence of the connection between basic research and social and economic value. R&D improves understanding of hazard phenomenology, and in principle, this knowledge supports enhanced loss reduction strategies. However, the data to document the connection are often lacking, and this fuels concerns about implementation gaps. We emphasize that efforts to document the connection between research efforts and loss reduction would likely encourage implementation and would provide policymakers with a concrete means of identifying the programs that are most effective.

THE CURRENT R&D PAYOFF

Together, the above factors create a difficult planning environment for hazard loss R&D. Without metrics to assess the effectiveness of R&D and in the presence of strong social biases that tend to de-emphasize R&D in loss reduction strategies, decisionmakers are challenged to evaluate the "payoff" from research programs. This problem is further compounded by fundamental ambiguities in quantifying R&D levels, as discussed in Chapter Two.

In this policy setting, the most prominent hazard loss reduction R&D seems to focus on known and demonstrable loss reduction strategies, such as evacuations and short-term warnings. The goal of this R&D is essentially to improve existing weather forecasting capabilities. But, as discussed in Chapter Three, the loss reduction contributions of these efforts are limited. While improvements in hurricane warning technology enable messages to be disseminated more widely and more quickly, giving individuals more lead time to turn off electricity and main water valves and close and board up windows before exiting an area, these efforts offer only modest hazard loss reductions. Dramatic improvements in making communities more resistant to natural hazards occur not in the short term, but during the mitigation phase.

Further, as also noted in Chapter Three, loss reduction benefits from operational support programs are largely indirect because it is difficult to differentiate the contributions of R&D from those of operations, making the payoff unclear. And because these programs are predominantly forecast-focused, their reduction successes (e.g., moving individuals out of harm's way) also occur primarily in the short term.

This policy environment has also created confusion about the appropriate role and structure for standalone loss reduction R&D programs. These programs have faced damaging criticism for weighting scientific research over applications (e.g., the criticisms of NEHRP in the aforementioned OTA report for contributing to an implementation gap). This charge highlights the difficulty of focusing on R&D as a loss reduction strategy—the human factor again intervenes. Might the difficulty with evaluating the payoffs of R&D correspond to the problems R&D is being asked to solve? That is, should the question of implementability be factored into the problem the government presents to R&D? The effectiveness of R&D in any area, after all, relies on the willingness of individuals or communities to implement its findings. The OTA report addresses this difficulty, asserting that

> NEHRP's approach can be thought of as supplying information on earthquake risks and possible countermeasures to those who may wish to mitigate. By supplying this information, the program hopes to motivate individuals, organizations, and local and state governments toward action while providing guidelines on how to proceed. This approach implicitly assumes that the interest or incentive for mitigation is sufficient for people to act on such information. However, the current paucity of mitigation activities suggests that individuals, organizations, and local and state governments lack sufficient incentives for mitigation. Whether or not the federal government should play a role in ensuring that there are sufficient incentives for mitigation is a sensitive policy question. (U.S. Congress, OTA, 1995, pp. x–xi)

As with all R&D, the success of these hazard loss reduction endeavors is proportional to the willingness of policymakers to act on them. The OTA study cites a survey showing that the dissemination of studies of historical earthquake activity and assessments of current vulnerabilities of states is crucial to encouraging local mitigation measures (U.S. Congress, OTA, 1995, pp. 114–116). Such earthquake studies and assessments obviously must be the result of research, reasserting the need for ongoing R&D. But, again, the more researchers and hazard programs can emphasize the payoff from carrying out the mitigation measures their findings identify, the more likely policymakers are to put those measures into practice.

The problems discussed above are reminiscent of Donald Stokes's analysis of the policy challenge for supporting "use-inspired" research efforts—that is, research programs that are nominally focused on solving important social problems, such as reducing the losses from natural hazards. In his book *Pasteur's Quadrant,* Stokes contrasts the policy challenge for use-inspired research to the long-standing U.S. approach to R&D that was established with Vannevar Bush's 1945 report *Science, the Endless Frontier.* Originating with a request from President Roosevelt for a national strategy on scientific research, Bush's plan was deeply influential for many years, as the United States established scientific research agencies following World War II. To this end, the report made two influential statements, both of which are countered by Stokes. First, Bush stated that basic research is "performed without thought to practical ends," and second, he called basic research the "pacemaker of technological progress." Although such a result was not strictly Bush's intent, his report yielded an endlessly cited one-way model for transforming scientific research into practical use in the form of new technology. That is, basic research is fed into applied research, which then leads to development and finally production and operations.

Stokes argues that for use-inspired research programs, the linear model is overly simplistic and in fact bears little resemblance to the far more complex, multidirectional way research is conducted and transferred to practical applications. Further, he takes issue with the notion that basic research and applied research carry discrete and independent goals—fundamental knowledge and use, respectively. As a counterexample, Stokes points to Louis Pasteur's simultaneous efforts toward a better understanding of disease and the application of this understanding to prevent illness and spoilage. Pasteur's work had long-lasting impacts for both so-called "pure" science and public health. The binary model of basic and applied research thus breaks down.

Rejecting the linear model, Stokes argues for a new paradigm, his "Pasteur's Quadrant," which he visualizes as a matrix with four quadrants (Figure 4.1). The vertical axis asks if the research is inspired by a quest for fundamental understanding, and the horizontal asks if it is inspired by consideration of use. The model thus allows for quadrants for pure basic research (e.g., Niels Bohr's pursuit of a model atomic structure), use-inspired basic research (e.g., that of Pasteur), and pure applied research (e.g., that of Thomas Edison). As the matrix illustrates, Stokes posits a new compact between science and the federal government that balances understanding and use and that allows for greater permeability between conceptions of basic and applied research.

In Stokes's analysis, the traditional view of basic research limited its value in terms of solving social problems because many of the programs supporting this kind of R&D are not structured to differentiate research efforts, as is done in Figure 4.1. Instead, there is an ongoing risk that the funding of basic research will be seen as contributing to a cloistered environment with no thought to societal needs. This risk in turn leads to a lack of coordination across "science" and "mission" programs, which hamstrings

		Consideration of use?	
		No	Yes
Quest for fundamental understanding?	Yes	Pure basic research (Bohr)	Use-inspired basic research (Pasteur)
	No		Pure applied research (Edison)

Figure 4.1—Pasteur's Quadrant

mission agencies that feel obligated to fund only research that clearly falls within the "applied" category.[6]

Borrowing from Stokes's analysis, we conclude that the linear model of basic research to applied research to development poses a major challenge for measuring the payoff from hazard loss R&D. In our view, this model places a disproportionate value on R&D related to weather forecasting systems, which are seen as the technological endpoint of a line of research efforts, a model of perfect linearity. In turn, other kinds of hazard loss reduction research may suffer from a perceived lack of direct (or linear) social benefit. Given this situation, a means by which to demonstrate the socioeconomic value of all kinds of hazard studies would be of great help. If a particular kind of R&D for a particular kind of hazard can be shown to save X number of lives and X number of dollars, the incentive to support studies and put their findings into practice/policy becomes far stronger. Transformations in public perception can, after all, occur. As Pielke points out, global climate change shifted from an "esoteric scientific issue" to an "international problem" once temperature trend data were "associated with societal impacts of climate" (Pielke, 1996, p. 258) and its position on the public policy agenda became increasingly prominent. Thus, perhaps other neglected areas might take a place at the policy table if an R&D strategy were to be crafted that considers not just the activities that offer the most easily demonstrable short-term payoff, but also those efforts that promise a significant dividend if given commensurate funding and a level of policy attention that will lead to legislation (if necessary) and implementation.

As an illustration of the types of analysis that could lead to a stronger "use-inspired" framework for hazard loss R&D, a series of HAZUS simulations of the 1994 Northridge earthquake were conducted in a FEMA study of the benefits and costs of

[6]All other agencies that support science (e.g., DoD, NOAA, and NASA) do so only to further their agency mission. Stokes suggests that one effect of the postwar paradigm has been a hindrance of the upward movement of research in mission agencies from Edison's quadrant (pure use) to Pasteur's (use-inspired basic research) (Stokes, 1997).

seismic mitigation measures. The results showed that if the Los Angeles area had been built to high seismic design standards prior to the event, a comparable earthquake would have resulted in $11.3 billion less damage (FEMA, 1997, p. 37).[7] Development of seismic standards depends on ongoing R&D, the enhancement of simulation models, the development of shake tables, the collection of accurate loss data, and other efforts. The investment, however, portends substantial dividends. For example, since ground-shaking is responsible for the most extensive damage and fatalities during an earthquake, research that tests various engineering techniques for their potential to withstand strong shaking could save lives and dramatically reduce property damage.[8]

It appears, then, that the present allocation of federal dollars may not be guided by demonstrable payoffs. While weather forecasts have a well-documented economic value (see Chapter Three), when one considers the *amount* of funding R&D on forecasting receives compared with funding for R&D on weather-related *losses*, there is a noticeable imbalance. It is undoubtedly difficult for policymakers to justify a shift in priorities in the face of the everyday-use value of forecasts combined with the daunting land use planning and lifestyle overhauling other mitigation efforts demand—once again, the challenge involves issues of human will. But in the short term, what can be improved is the set of tools policymakers have at their disposal, in relation to both needed information and key standards by which to balance the portfolio more productively. These necessary tools, however, address only immediate obstacles. For the longer term, the federal government needs to take a long, hard look at its expectations for R&D and the effects of those expectations on its success, a point on which we elaborate in Chapter Five.

KEY STEPS FOR POLICYMAKERS

Our analysis leads us to conclude that the current portfolio is problematic in its overemphasis on short-term prediction and weather-related hazards. Further data that could be used for a comprehensive prioritization of R&D efforts are lacking. And finally, there are fundamental ambiguities for an R&D budget analysis, creating significant difficulties for a coordinated policy planning process. In this light, we emphasize four key steps that would enable policymakers to fortify their hazard loss R&D decision process and thus, ultimately, increase the contribution of R&D to loss reduction. The steps are discussed below.

---

[7]These figures do not take into account the cost of building to these higher seismic design standards, which are small compared to total construction costs (see Meade, Kulick, and Hillestad, 2002). The FEMA report, however, notes that "resulting losses are still significantly lower than the losses that would be anticipated from a similar event in the greater urbanized areas of downtown Los Angeles (for example, a 6.7 Santa Monica or Newport-Inglewood event)" (FEMA, 1997, p. 37).

[8]This is not to suggest that imagined rates of return generated by, for instance, a benefit-cost analysis, should become the key measure in R&D allotment decisions. In his study of various attempts to measure the economic and societal payoff of R&D, Popper (1999, p. 44) warns that quantifying the complexities of scientific research into a hard number can be dangerous, in that it suggests to policymakers that such research is easily controlled and that the research process is exceedingly straightforward. Such a perception can backfire on researchers, as it creates an untenable and oversimplified model of what is inherently a murkier and less predictable process.

Establish a comprehensive loss database. The federal government, the insurance industry, researchers, engineers, citizens living in high-risk areas, and virtually all taxpaying citizens have a vested interest in improved loss estimates. Unfortunately, as stated earlier in this chapter, loss data are still diffusely collected by a variety of federal agencies and private insurance companies, with no standardized framework in place to guide the collection effort. Thus, the major hurdle in achieving a consistent dataset is not merely the array of sources but the problem of identifying precisely which data should be included in an estimate (NRC, 1999, p. vii). These data are central for a host of concerns, including prioritizing R&D efforts, planning state and local budgets, developing contingency operations, and conducting benefit-cost analyses for specific mitigation measures that would allow policymakers to see the relative value of various R&D efforts. As stated earlier, the NRC report and the Heinz report both offer detailed recommendations for data-collection improvements and strategies, including ways the data could be organized and the sources that should be tapped (e.g., insurance trade associations). Indeed, a comprehensive loss database would be of undeniable value to policymakers for hazard mitigation efforts, and it would also assist in comparisons of government and private insurance payouts. The NRC report suggests that this information might encourage uninsured individuals or businesses to purchase insurance rather than relying on government assistance that will probably not be as comprehensive or as timely as they anticipate (NRC, 1999, p. 24). Ironically, the data problem appears quite surmountable. As previously discussed, detailed recommendations on how to create and operate a national loss database and how to gather the data in a uniform way are already available (i.e., in the NRC and Heinz studies); they need only be carried out.

Use loss modeling as a tool to identify essential R&D. As discussed above, loss modeling uses statistical models to describe a range of possible damage states in response to hazard events with a defined probability of occurrence. As such, it can help determine which hazards generate the greatest avoidable losses, the effects of various mitigation procedures on loss totals, the time scale for losses, and the budget needed for vulnerable regions to prepare for a prospective hazard. Once a national database is in place, such modeling will be even more precise, but we already possess techniques that would enable great headway to be made in prioritizing research needs by weighing the costs and benefits of various mitigation measures against the estimated losses from specific hazards. We need only make better and more wide-ranging use of them.

Reorient R&D distribution toward longer-term loss reduction efforts. This is especially relevant for weather-related hazards, for which R&D is primarily limited to procurements for short-term forecasting efforts. Even in the absence of a capability to determine specific payoffs for various R&D efforts, the present emphasis on short time scales is clearly circumventing more-lasting solutions. The recent accent on research into global climate change patterns can translate to longer-term predictions (e.g., there will be more hurricanes next year), but such estimates offer people little incentive to act on this information; warnings of weather extremes a year away tend to have minimal influence on individual decisionmaking. Thus, in practice, much of climate change R&D is focused on short-term forecasts, which do not result in significant loss reduction. A shift to longer-term and less prediction-oriented efforts, with a focus on investigations and technologies to make the built environment and infrastructures more resilient, holds great promise. Such R&D promises to save lives, protect property, and dramatically reduce the costs of rebuilding after a disaster.

Increase focus on technologies/information to reduce infrastructure losses. A commitment to longer time scales would pave the way for a greater R&D emphasis on infrastructure improvements. Damages to infrastructure—e.g., buildings, public roads and highways, bridges, water and sewer treatment plants, emergency services—result in casualties as well as extensive economic losses. The development of improved technologies and information systems could help limit such losses. For instance, greater R&D focus on funding for communications and remote-sensing capabilities, GIS, GPS, and modeling and simulation techniques promises to lead to considerable damage reduction. At the most basic level, improved information on hazard phenomenology can be incorporated into building codes and engineering practice. This mode of R&D has accelerated in recent years in the case of earthquakes, but it seems to be lacking for weather-related hazards. In the area of technology development, sophisticated simulation models could help engineers improve the resilience of structures. Indeed, a current NSF project seeks to create an integrated network that will enable scientists and engineers to collaborate on the development of sustainable structures to minimize earthquake damage and casualties. The network will give users remote access to up-to-date databases, simulation software, and models.[9] Such efforts not only work toward mitigation, but also encourage implementation by placing researchers and engineers—and potentially policymakers—in active collaboration. In many cases, infrastructure-focused mitigation R&D may be less expensive than current efforts, providing a higher "rate of return" on the federal investment.

Of course, these are only first steps. In the case of of loss modeling alone, capabilities must be developed to chart with reasonable precision the long-term effects on commercial industry, emergency infrastructure repair, residential reconstruction, utility losses, employment levels, and a range of other components. And a rigorous crosscutting analysis of R&D activities to improve understanding of their contributions to hazard loss reduction is needed to support the above recommendations. But these proposed steps offer a strong beginning and could lead to a more balanced, cost-effective, and discerning allocation spread.

It is important to keep in mind that R&D expenditures are small in comparison to expected losses from future hazards. Currently, R&D appropriations amount to about 5 percent of the federal budget, or a little over $100 billion per year, and more than half of the funding is dedicated to defense R&D (AAAS, 2002). Only about $1 billion is allocated to hazard loss reduction *per year*, while the costs of natural hazards average hundreds of millions of dollars *per week*. In view of this disjuncture, a strong case could be made for a more substantial investment. At present, however, definitively quantifying the contribution of R&D to hazard loss reduction is infeasible because of the lack of available data, as outlined above. Despite its investments (albeit limited) in hazard loss reduction R&D, the government has yet to establish the essential

[9]For more information about this program, which is a component of the George E. Brown, Jr., Network for Earthquake Engineering Simulation, see <http://www.eng.nsf.gov/nees/>.

framework that would allow these efforts to operate efficiently and show their own merit. Specifically, there is currently no means by which to determine the effectiveness of the current R&D portfolio, the loss reductions facilitated by R&D, or the most productive allocation of funds across R&D efforts.

While these steps are critical, they are essentially improvements to the existing R&D effort. They do not address perhaps the most fundamental obstacle of all to the success of that effort's contribution to hazard loss reduction—that is, whether the right questions are being asked of R&D. In the face of rising hazard costs and increasing societal vulnerability, what exactly is it that R&D is expected to do? These questions are the focus of Chapter Five.

Chapter Five

SUMMARY AND CONCLUSIONS

Policymakers face a complex environment in making hazard loss R&D funding decisions. In the previous chapter, we highlighted the need for several essential first steps: establishing a loss database, using loss modeling in making allocation decisions, and reorienting the R&D portfolio toward longer-term mitigation efforts and the use of science and technology for infrastructure improvements. Now, we conclude by addressing a philosophical issue that has emerged repeatedly throughout our analysis. Specifically, we consider on a more conceptual level the expectations for federal hazard loss R&D. What, after all, is hazard loss R&D being asked to accomplish? Are the right questions, in fact, being asked of it?

THE CONTRIBUTION OF R&D TO HAZARD LOSS REDUCTION

With losses from natural hazards escalating, the federal government faces a dilemma. Maintaining the status quo will have growing negative implications for regional economies and the federal budget. But what role, precisely, should federally funded R&D play in reducing hazard losses? What can it offer that policy attention, legislation, code enforcements, and land use strictures cannot? More broadly, what is it expected to do?

At present, as discussed throughout this report, although hazard loss R&D may not be able to eliminate all hazard losses, it can certainly make significant progress in limiting avoidable losses—those that could be prevented if specific measures were taken. R&D is also critical for adapting federal response to the changing nature of hazard losses. As citizens increasingly inhabit vulnerable regions and as communities continue to develop in high-risk areas, the hazard loss potential soars. Thus, R&D that continuously responds to societal trends is crucial.

Unfortunately, investments in R&D are receiving increasing criticism that federal support is too great or that the payoff is too scant. In this environment, the call to demonstrate in concrete terms the value of federal R&D is becoming increasingly urgent. As discussed in Chapter Four, however, establishing the rate of return on scientific research is difficult. Connecting basic research—research conducted without an application in mind—to a measurable outcome is particularly problematic. Basic research is meant to contribute to the larger body of knowledge, so the ultimate applicability of its findings may be years away or merely impossible to chart because such findings may feed into applied research that loops back into more basic research, and so forth, in a fundamentally dynamic process.[1]

The challenge for those carrying out hazard loss research has been amplified by the decline in the federal government's share of national R&D investment and growing demands that federal agencies demonstrate the efficacy of their R&D programs.[2] The passage of the Government Performance and Results Act in 1993 dramatically highlighted the change: The Act requires agencies to assess the performance of their R&D efforts. Under these conditions, important basic research into natural hazard characteristics could be abandoned if its "real world" value cannot be demonstrated to the satisfaction of budget authorities.

Thus we face an impasse. The present hazard loss R&D portfolio appears unbalanced, but an informed or justifiable shift in strategy requires data and a framework that are as yet unavailable. In turn, R&D's contribution to hazard loss reduction appears considerable, but once again the data necessary to establish its value or to isolate precisely which kinds of R&D contribute the most are lacking. Could the impasse derive from the expectations for R&D? In other words, what exactly is R&D being asked to do? Are the demands being placed on R&D misguided, dooming its efforts to failure? Indeed, one must consider whether the problem being framed for R&D to address is in large part to blame for the current muddled allocation.

What Is Being Asked of R&D?

Rising hazard losses have been the focus of various conferences, committees, working groups, panels, and consortiums that have posed potential solutions and have generally sounded alarms. The concern of interest, however, is not finding the "solution" to hazard losses, but identifying what R&D should be asked to do. That is, the federal government has an asset to deploy in R&D. Currently, that asset is deployed haphazardly and perhaps injudiciously. The problems hampering improved deployment fall into two categories: (1) the practical and quantitative limitations outlined in the previous chapter, in particular the lack of loss data and the tilted allocation of funding; and (2) the philosophical issues, in particular, the nature of the problems R&D is being asked to solve. Thus, in addition to practical limitations, hazard loss R&D faces larger, theoretical ones. Even the improvement of loss data and modeling and a reorienting of the allocation spread toward longer-term efforts do not guarantee a more coherent and judicious distribution or a more lucid role for R&D in national efforts to reduce hazard losses. A bigger issue emerges: What is

[1]Interestingly, public support for R&D investment appears to be quite strong. Eighty-two percent of the respondents to a 1999 NSF survey agreed with the following statement: "Even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the Federal Government." Only 14 percent thought that government spending on scientific research was too great, while 37 percent thought the government was not spending enough (NSB, 2002).

[2]This pressure has led to a series of efforts to quantify the value of R&D. In 2002, for example, OMB introduced its Program Assessment Rating Tool (PART) to evaluate program performance, including agency R&D and S&T budget requests. PART came about via efforts by the Bush administration and OMB to strengthen program accountability and develop metrics for evaluating federal R&D funding programs and priorities. For the 2004 budget, OMB used PART to review about 20 percent of federal funding.

wanted from R&D and how does what is asked of it affect the contributions it is able to make?

The role of federally funded R&D has been a source of constant debate in this country, particularly in the half-century since the publication of Vannevar Bush's influential 1945 report *Science, the Endless Frontier*, which proposed a national strategy for scientific research following the enormous boom in federally supported research during World War II. The ensuing deliberations and disputes over the links between societal problems and scientific research have led to numerous attempts to characterize, quantify, and otherwise frame the various responsibilities of federal R&D, the government agencies that distribute R&D funding, and the scientific endeavors themselves. Donald Stokes's important contribution to this ongoing debate—Pasteur's Quadrant—was one of many, including the recent categorization of research into Baconian (mission-oriented or applied), Newtonian (research for knowledge's sake), or a third type that combines both, Jeffersonian (see Holton, 2001). Lewis Branscomb (1990) in turn has raised the issue of the environment in which research is carried out (i.e., how open it is to creativity), while also distinguishing between the character of the research process itself (e.g., basic research, problem-solving research) and the goals of the research sponsor (whether the sponsor expects the research to be knowledge-seeking or anticipates direct benefits).

Large-scale efforts to eliminate the binary categorization of basic and applied research led, in 1995, to a major study by the National Academy of Sciences Committee on Science, Engineering, and Public Policy which recommended that the federal government segregate R&D activities in the federal budget under the FS&T heading. The goal was to distinguish research and fundamental technology development from the production, maintenance, and testing of weapons systems. The committee expressly stated that the FS&T definition "deliberately blurs any distinction between basic and applied science or between science and technology." In a direct rejection of the Cold War–era model, the authors asserted, "A complex relationship has evolved between basic and applied science and technology. In most instances, the linear sequential view of innovation is simplistic and misleading. Basic and applied science and technology are treated here as one interrelated enterprise" (Committee on Science, Engineering, and Public Policy, 1995, p. 5).[3]

In fact, there is widespread dissatisfaction with the long-standing binary categorizations of research and the overly simplistic view of the way science works and research operates. Stokes's new paradigm of Pasteur's Quadrant, discussed in the previous chapter, presents a more realistic and fertile view of R&D's role in the characterization of use-inspired basic research. Ultimately, hazard loss R&D lies at the heart of this quadrant. It seeks to ameliorate a societal problem while also advancing knowledge. The categorization of use-inspired research demands a recalibration of the roles of government and science in order to correlate policy expectations with sci-

[3]Beginning in 2002, the federal budget began using an FS&T budget category, although it does not strictly correlate with the definition proposed by the National Academy of Sciences (NAS)—e.g., the category includes non-R&D components such as certain education and training programs. See Eiseman, Koizumi, and Fossum, 2002.

entific prospects and potential. Indeed, hazard loss R&D faces the same issues other R&D areas have faced because of inaccurate perceptions of the way research operates: unmanageable expectations, charges of inapplicability, and ongoing demands that a "cure" be delivered. At their base, these issues revolve around the role established, by plan or by default, for R&D in federal problem-solving. To examine this further, let us look at the policy expectations for R&D and their effect on R&D's contribution to the societal problem of rising hazard losses.

What Is Being Asked of Hazard Loss R&D?

The societal problem of hazard loss, like all societal problems, frustrates a simple linear approach that links one clear concern to a logical, all-purpose solution. As Figure 5.1 illustrates, policymakers confronting hazard loss R&D decisions face a complicated, dynamic climate—one that thwarts any attempt to draw linear and direct connections between the problem (hazard losses) and the proposed solution (R&D that eliminates or drastically reduces such losses).

Specifically, the current climate is characterized by a series of confounding factors, some of which seek to ameliorate the problem, while others obfuscate it:

- *Societal vulnerability to hazards and the consequent hazard losses are both increasing.* Population migration to high-risk areas and the accompanying development have put more and more people and property in harm's way.
- *Society and individuals are taking steps to reduce vulnerability.* Various mitigation and evacuation strategies are currently in place to offset some of the dangers of future hazards.

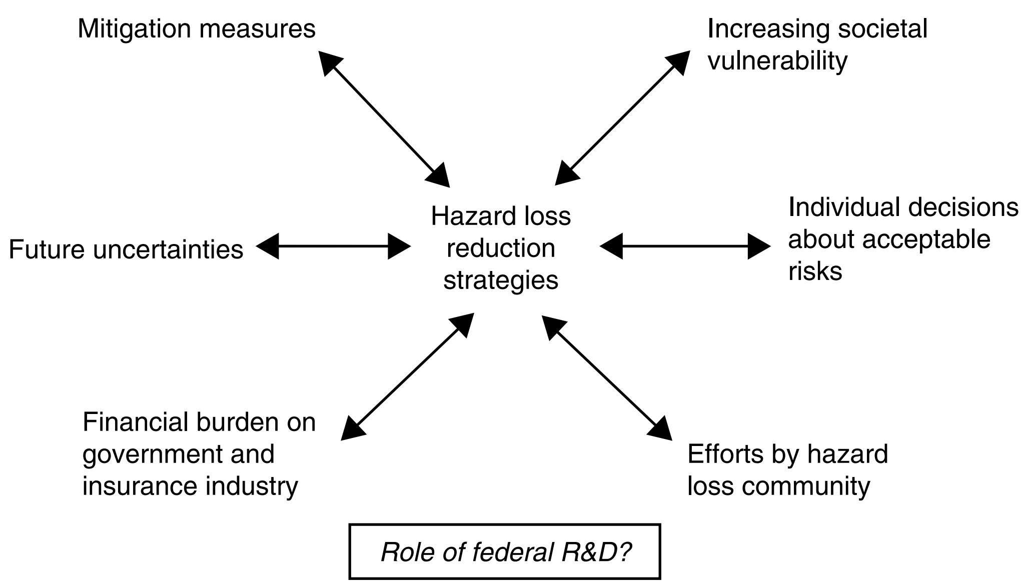


Figure 5.1—Factors Influencing Hazard Loss Reduction

- *Future uncertainties remain.* Any steps taken to reduce vulnerability are complicated by the unknown, such as long-term climate change and the actual probabilities of hazard occurrence.
- *Individuals make choices based on acceptable risks.* Individuals will inevitably choose to live in vulnerable areas, weighing the potential dangers against the advantages of a given location and often using private hazard insurance to offset any associated economic risks.
- *The financial burden borne by government and insurance companies is growing.* Because both the federal government and the insurance industry bear massive costs in the aftermath of a disaster, both have a mounting economic incentive for reducing losses, thus spurring their efforts to do so.
- *The hazard loss community continues to attempt to solve the problem.* Various organizations, researchers, and federal agencies remain dedicated to formulating strategies, raising alarms, and attempting to spur more-comprehensive solutions.

All of these factors create a dynamic environment of pushes and pulls. Policymakers are by no means facing a static situation in which they can merely plug in various solutions to the problem; they confront a dynamic system. Given this environment, it should come as no surprise that the current state of hazard loss reduction efforts—and the role of R&D within them—is haphazard and uncoordinated. Indeed, given the array of forces at play, it is not at all clear that government can "solve" the problem of rising hazard losses as currently framed. Many aspects of the problem are still impossible to grasp and, as discussed in terms of loss data, largely unquantified. In addition to this tangled assortment of factors, a series of ongoing questions and uncertainties further impinge on a coherent and cohesive hazard loss reduction strategy. Specifically,

- *The quantitative understanding of vulnerability is limited.* Understanding is limited by loss data deficiencies and poor understanding of hazard impact, especially in complex urban areas.
- *It is unclear what fraction of losses can be reduced.* Indeed, segregating avoidable losses from unavoidable losses is difficult, particularly in light of societal vulnerability, the density of infrastructure, and the willingness of individuals to take vaguely calculated risks.
- *Some losses will never be eliminated.* Given that no amount of science can stop natural hazards from occurring and given that humans will continue to settle along coastlines and fault lines as well as in areas vulnerable to forest fires, there will always be some amount of loss.
- *Science will never reduce all uncertainties associated with hazards.* Any expectation that science will inevitably allow the accurate prediction of all hazards dooms R&D to failure. While science can doubtless make improvements, it will likely never produce a state of complete certainty where natural hazards are concerned.

- *Technical information makes limited contributions.* While of significant use value, no amount of satellite data, remote-sensing capabilities, GPSs, or data accumulation can truly slash hazard losses; human behavior will still intervene. Technology and the information it generates are useful only to the extent that they are acted on.
- *In this environment, it is unclear which kinds of losses R&D can or should target.* We have presented significant evidence that the current focus is tilted toward weather forecasting and that hazard loss R&D should move toward longer-term solutions and to other kinds of hazards (especially earthquakes). But the relative contributions R&D can make are still unestablished without the missing metrics.

Within such a dynamic atmosphere and given these uncertainties, policymakers face less a geophysical problem than an inherently *societal* problem with a geophysical underpinning. Any strategy to attack this problem thus requires not just geophysical research but the kind of all-encompassing strategies that would be used to confront any other large-scale societal problem. It is necessary to distinguish between the massive national and even global crisis of rising hazard losses and the way this crisis is transformed into a specific "problem" R&D is being asked to tackle. Our analysis, in fact, suggests that the current conception of the problem may be the source of many of the difficulties in the current R&D funding allocation. That is, the problem that has been laid at the feet of R&D may in fact be unclear and inappropriate.

THE PROBLEM WITH THE PROBLEM

The danger for hazard loss R&D in particular is that it may be being asked or expected to "solve" hazard occurrence, that is, to predict hazard events with complete accuracy. As discussed in Chapter Three, there exists a widespread societal belief that science means uninterrupted progress toward greater and greater predictive accuracy until a state of complete certainty about the future is reached. Such views doubtless feed into the way that problems scientific research is expected to solve are formulated. They thus have a lasting effect on R&D investment, expectations, and assessment. Most obviously, the reigning emphasis on forecasting is driven by a belief that the hazard loss problem to be solved is enhanced hazard prediction. We want to suggest, however, that this approach may be the source of many of the allocation problems discussed in previous chapters. Therefore, we propose an alternative framework for considering hazard loss R&D. In this framework, the following parameters are used to identify the qualities of R&D activities that are most likely to make the largest contribution to loss reduction efforts:

- *Implementation of R&D results should be straightforward.* Specifically, the R&D problem should be framed in a way that allows the findings to be put into practice. The most obvious examples for hazard loss R&D would be efforts to improve evacuations. The rub, of course, is that actual implementation still relies in part on human behavior, as discussed in Chapter Four. For this particular example, it is also important to recall that evacuations address only a small portion of the potential hazard losses. Other examples of implementable results include measurements of hazard phenomena that can be incorporated into engineering studies and loss modeling that can be incorporated into mitigation plans.

- *R&D should be focused on "solvable" problems.* In earthquake science, an effort has been made to differentiate the types of uncertainty that drive research. With this approach, *epistemic* uncertainty refers to problems that are beyond the realm of current knowledge but whose solutions could be ascertained with focused research and/or data gathering. In contrast, *aleatory* uncertainty refers to intrinsic uncertainty that is inherent in the phenomenon itself. Detailed descriptions of the ground-shaking during a large earthquake would be characterized as epistemic uncertainty (because ground-shaking can be measured, in principle). In contrast, the date of the next large earthquake in Los Angeles would be an example of aleatory uncertainty, because there are currently no foreseeable ways to predict future earthquakes at this level of accuracy. Generalized to hazard loss R&D, these distinctions are important because natural hazards involve complex dynamic systems and there is great social interest in predicting their behavior. That is, social pressures may drive R&D toward problems that are aleatory in nature and hence not rewarding as a research strategy. From a policy perspective, difficulties arise when there is a lack of consensus on the issues that are aleatory versus those that are epistemic. As an example, consider the controversy over R&D progress on forecasting hurricane tracks, which are used to issue evacuation alerts. Analysis of 30 years of data shows that there has been very little improvement in the precision of the 24-hour forecast, despite billions of dollars of expenditures for R&D on this problem and the deployment of new data-gathering infrastructure (Franklin, McAdie, and Lawrence, 2002). At the same time, news stories have appeared in the scientific press describing excitement in the research community, breakthroughs that are in the offing, and the possibility of significant changes in forecasting capabilities.[4] These articles have prompted skeptical comments from critical members of the scientific community.[5] In our view, uncertainty over aleatory and epistemic issues severely limits the effectiveness of hazard loss R&D.
- *Expectations for the role of discovery should be clear.* There should be agreement about the expectation that a major, unpredicted discovery may emerge that will transform the state of science in a given area. Often, too much emphasis is placed on the prospect of a historic finding that will serve as a panacea for a given problem. In such an environment, less-groundbreaking contributions are doomed to minor status (and perhaps minor funding). It should be clear from the beginning whether policymakers are banking on a "magic potion," or whether there is a belief that if researchers collect the appropriate data and do the analysis, progress can be made (see below) and the effort may lead to a discovery that makes a problem seem more solvable.
- *Progress should be identifiable.* Is the problem framed in such a way that researchers are working with an end goal perpetually in sight or at least with an eye

[4]See, for instance, Kerr, 1999.

[5]See Pielke, 1999.

to signposts or indicators along the way? If so, progress can be marked along the way, and ultimate contributions will be clearer. In many ways, this characteristic conflicts with the expectation-of-discovery principle. The relationship between the two in terms of problem definition and R&D expectations should be clearly outlined by policymakers developing the R&D portfolio. Are they framing the problem so that a failure of uncharted exploration to elicit a major innovation is acceptable? Or, given their expectations, might it be better to frame the problem in terms of more measurable progress, even if the prospects for bold discovery are diminished?

Ultimately, the question of how, or even if, R&D should be used to solve problems will be a long-debated one. But framing the problem in the above terms provides a means by which R&D can be organized and coordinated and by which its contributions can be viewed much more clearly. There are problems that are well solved by R&D, but they need to be specified at the outset in order to develop, organize, and oversee an R&D strategy. In this way, the expectations are established and the channels by which contributions should be measured are clear from the outset.

Obstacles both practical and philosophical have stood in the way of a more successful hazard loss R&D strategy. We have offered ways to ameliorate both types of obstacles via specific steps (improving loss data and modeling, shifting the time scale of the portfolio) and a more thoughtful framework for establishing the role of R&D within a larger hazard loss reduction strategy.

SAMPLE RaDiUS RECORD

RaDiUS ID: 50111012411	**Award/Task Number:** 0122124	**SBIR Award:** N
Type of Funding Mechanism:	Extramural / Grants / Project	
Estimated Start/End Dates:	Sep 2001 to Aug 2003	
Performer:	VIRGINIA POLYTECHNIC INSTITUTE	
Performer Type:	Public Educational Institution	
Performer Location:	Blacksburg, VA	
Contact Name:	Donatus C. Ohanehi, dohanehi@vt.edu	
Phone:	540/231-6000	
Place of Performance:	Blacksburg, VA	
Funding:		
Total Federal Funding for All FYs	$149.4K	
Average FY Federal Funding	$49.8K	
Average Monthly Federal Funding	$6.5K	
FY 2001 Actual Funding	Federal: $149.4K; Non-federal: $0.0K	

TITLE: Partnership for Advancing Technologies in Housing: Advanced Replacements for Mechanical Fasteners in Housing Construction for High Wind Zones

SHORT DESCR: PARTNERSHIP FOR ADVANCING TECHNOLOGIES IN HOUSING: ADVANCED REPLACEMENTS FOR MECHANICAL FASTENERS IN HOUSING CONSTRUCTION FOR HIGH WIND ZONES

LONG DESCR: NSF PROPOSAL # 0122124, ADVANCED REPLACEMENTS FOR MECHANICAL FASTENERS IN HOUSING CONSTRUCTION FOR HIGH WIND ZONES

ABSTRACT: Adhesives offer several design benefits over conventional mechanical fasteners, including nails and rivets. The acrylic foam tape is a unique adhesive product that requires no curing and yet offers substantial property advantages for certain semistructural applications. Virginia Tech proposes to implement an innovative assembly process in the construction industry through the development of materials, design, and application databases. The assembly process will be based on generic acrylic foam tapes, and the test bed will be shear walls and diaphragms in light-frame construction for wind-critical areas, a very large market segment. The assembly process meets PATH (Partnership for Advancing Technology in Housing) goals of promoting housing affordability, durability, and wind-damage resistance. PATH's technical areas addressed are "advanced panel systems" and "whole-house and building process redesign." The fundamental research component of the project will generate material data, with emphasis on tape durability. Numerical structural modeling and cyclic tests of the assemblies will provide a basis for showing the adequacy of the tape to resist the dynamic loads associated with high wind events. A design methodology will be developed to enable field engineers to recommend and direct successful tape applications at construction sites. Shear wall and diaphragm models will be constructed for testing and demonstration. Walls and diaphragms will be designed to take full advantage of load redistribution capabilities, increased flexibility and damping, and improved fatigue resistance provided by the tapes. The advantages of the resilient foam tape in wind-critical applications will be highlighted as meeting the PATH goal of improved disaster resistance. The application of the tape increases overall system stiffness and increases the resistance of the roof sheathing to wind uplift from hurricane loading, and tape sealing reduces water damage, the major property damage under hurricane conditions. In addition to simplifying the assembly/construction process, the design may offer enhanced performance, including longer life, better appearance, reduced transportation costs, and environmentally friendly alternatives over the use of conventional fastening systems. Collaboration with the National Association of Home Builders (NAHB) through the PATH program will facilitate timely interactions with end users of technologies developed in the project and will speed up widespread adoption. A national homebuilder company will build a demonstration home if laboratory tests show feasibility. The output of the project will be materials, joint performance, and application data on a simple but innovative assembly process. The databases and demonstration models will be focused on specific applications for wind-critical areas but will be applicable to a broad range of advanced adhesive tapes for use in housing construction.

REFERENCES

American Association for the Advancement of Science (AAAS), *AAAS Reports XXVII: Research and Development FY 2003*, Washington, DC: American Association for the Advancement of Science, 2002.

Branscomb, L. M., "From Science Policy to Research Policy," in L. M. Branscomb and J. H. Keller (eds.), *Investing in Innovation: Creating a Research and Innovation Policy That Works,* Cambridge, MA: MIT Press, 1990, pp. 112–139.

Brooks, Harold, and Charles A. Doswell III, "A Brief History of Deaths from Tornadoes in the United States," *Weather and Forecasting*, 2001. Online at http://www.nssl.noaa.gov/~brooks/deathtrivia/ (as of February 10, 2003).

Bush, Vannevar, *Science: The Endless Frontier*, A Report to the President by the Director of the Office of Scientific Research and Development, Washington, DC: U.S. Government Printing Office, July 1945.

Changnon, Stanley A., David Changnon, E. Ray Fosse, Donald C. Hoganson, Richard J. Roth, Sr., and James M. Totsch, "Effects of Recent Weather Extremes on the Insurance Industry: Major Implications for the Atmospheric Sciences," *Bulletin of the American Meteorological Society*, Vol. 78, No. 3, March 1997, pp. 425–435.

Changnon, Stanley A., Roger A. Pielke, Jr., David Changnon, Richard T. Sylves, and Roger Pulwarty, "Human Factors Explain Increased Losses from Weather and Climate Extremes," *Bulletin of the American Meteorological Society*, Vol. 81, No. 3, March 2000, pp. 437–442.

Committee on Science, Engineering, and Public Policy, *Allocating Federal Funds for Science and Technology*, Washington, DC: National Academy Press, 1995.

Eiseman, Elisa, Kei Koizumi, and Donna Fossum, *Federal Investment in R&D*, Santa Monica, CA: RAND, MR-1639.0-OSTP, 2002.

Federal Emergency Management Agency, "FEMA Disaster Costs: 1990–1999." Online at http://www.fema.gov/library/df_7.shtm (as of February 10, 2003).

_____, *Report on Costs and Benefits of Natural Hazard Mitigation*, Washington, DC: Federal Emergency Management Agency, Publication 331, 1997. Online at http://www.fema.gov/pdf/library/haz_cost.pdf (as of February 10, 2003).

FEMA Mitigation Directorate, "HAZUS® 99 Estimated Annualized Earthquake Losses for the United States," Washington, DC: Federal Emergency Management Agency, 2001. Online at http://www.fema.gov/hazus/dl_eqpub.shtm (as of April 16, 2003).

Fossum, Donna, Lawrence S. Painter, Valerie Williams, Allison Yezril, Elaine Newton, and David Trinkle, *Discovery and Innovation: Federal Research and Development Activities in the Fifty States, District of Columbia, and Puerto Rico*, Santa Monica, CA: RAND, MR-1194-OSTP/NSF, 2000.

Franklin, J. L., C. J. McAdie, and M. B. Lawrence, "Trends in Track Forecasting for Tropical Cyclones Threatening the United States, 1970–2001," presentation at the 56th Interdepartmental Hurricane Conference, New Orleans, 2002.

General Accounting Office, "Hazard Mitigation: Proposed Changes to FEMA's Multihazard Mitigation Programs Present Challenges," *Report to the Chairman, Subcommittee on International Security, Proliferation, and Federal Services, Committee on Governmental Affairs, U.S. Senate*, Washington, DC: General Accounting Office, GAO-02-1035, September 2002.

H. John Heinz III Center for Science, Economics, and the Environment, *The Hidden Costs of Coastal Hazards*, Washington, DC: Island Press, 2000.

Hays, Walter W., "USGS Natural Hazards Programs: Lessons Learned from Reducing Risk," in U.S. Department of the Interior, *U.S. Geological Survey Fact Sheet FS-61-95*, 1995. Online at http://water.usgs.gov/wid/html/HRDS.html (as of February 10, 2003).

Holton, Gerald, "What Is the Imperative for Basic Science That Serves National Needs?" *Physics and Society*, Vol. 30, No. 2, April 2001, pp. 1–5.

Hooke, William H., "Statement of Dr. William H. Hooke," Natural Hazards Disaster Caucus Forum on Reducing America's Vulnerability to Natural Disasters, Washington, DC, June 21, 2000.

Hooke, William H., and Roger A. Pielke, Jr., "Short-Term Weather Prediction: An Orchestra in Need of a Conductor," in D. Sarewitz, R. A. Pielke, Jr., and R. Byerly, Jr. (eds.), *Prediction: Science, Decision Making, and the Future of Nature*, Washington, DC: Island Press, 2000.

Houghton, J. T., L. G. Meira Filho, B. A. Callender, N. Harris, A. Kattenberg, and K. Maskell (eds.), *Climate Change 1995: The Science of Climate Change*, Contribution of Working Group I to the Second Assessment of the Intergovernmental Panel on Climate Change, Cambridge, UK: Cambridge University Press, 1995.

Institute for Building and Home Safety, "Strong South Florida Building Standards Could Cut Storm Damage by Billions," press release, August 25, 2002. Online at http://www.ibhs.org/dg.lts/id.198/newsroom.view.htm (as of February 21, 2003).

Jarrell, Jerry D., Max Mayfield, Edward N. Rappaport, and Christopher W. Landsea, "The Deadliest, Costliest, and Most Intense United States Hurricanes from 1900 to 2000 (and Other Frequently Requested Hurricane Facts)," *NOAA Technical*

Memorandum NWS TPC-1, updated October 2001. Online at http://www.aoml.noaa.gov/hrd/Landsea/deadly/ (as of April 14, 2003).

Kerr, Richard, "Forecasters Learning to Read a Hurricane's Mind," *Science*, Vol. 284, April 23, 1999, pp. 564–565.

Knopoff, L., "Earthquake Prediction: The Scientific Challenge," *Proceedings from the National Academy of Science*, Colloquium Paper, Vol. 93, No. 9, April 1996, pp. 3719–3720.

Koizumi, Kei, Albert H. Teich, Stephen D. Nelson, and Joanne Padron Carney (in cooperation with the Intersociety Working Group, American Association for the Advancement of Science), *Congressional Action on Research and Development in the FY 2001 Budget*, Washington, DC: American Association for the Advancement of Science, 2000.

Kunkel, Kenneth E., Roger A. Pielke, Jr., and Stanley A. Changnon, "Temporal Fluctuations in Weather and Climate Extremes That Cause Economic and Human Health Impacts: A Review," *Bulletin of the American Meteorological Society*, Vol. 80, No. 6, June 1999, pp. 1077–1098.

Kunreuther, Howard, and Richard J. Roth (eds.), *Paying the Price: The Status and Role of Insurance Against Natural Disasters in the United States*, Washington, DC: Joseph Henry Press, 1998.

Landsea, C. W., N. Nicholls, W. M. Gray, and L. A. Avila, "Downward Trends in the Frequency of Intense Atlantic Hurricanes During the Past Five Decades," *Geophysical Research Letters,* Vol. 23, 1996, pp. 1697–1700. Online at http://www.aoml.noaa.gov/hrd/Landsea/downward/index.html (as of February 10, 2003).

Meade, Charles, Jonathan Kulick, and Richard Hillestad, *Estimating the Compliance Costs for California SB1953*, Santa Monica, CA: RAND, 2002. Online at http://www.calhealth.org/public/press/Article%5C103%5CFinal%20RAND%20Report.pdf (as of April 14, 2003).

Michael, A. J., S. L. Ross, D. P. Schwartz, J. W. Hendley, II, and P. H. Stauffer, "Major Quake Likely to Strike Between 2000 and 2030—Understanding Earthquake Hazards in the San Francisco Bay Region," *U.S. Geological Survey Fact Sheet 152-99*, 1999. Online at http://geopubs.wr.usgs.gov/fact-sheet/fs152-99/ (as of February 11, 2003).

Mileti, Dennis S., *Disasters by Design: A Reassessment of Natural Hazards in the United States*, Washington, DC: Joseph Henry Press, 1999.

Murphy, P. J., Lynn E. Davis, Timothy E. Liston, David E. Thaler, and Kathi Webb, *Improving Anti-Drug Budgeting*, Santa Monica, CA: RAND, MR-1262-ONDCP/NSF, 2000.

National Research Council, Committee on Assessing the Costs of Natural Disasters, Board on Natural Disasters, and the Commission on Geosciences, Environment, and Resources, *The Impacts of Natural Disasters: A Framework for Loss Estimation*, Washington, DC: National Academy Press, 1999.

National Science and Technology Council, Committee on the Environment and Natural Resources, and the Subcommittee for Natural Disaster Reduction, "Progress and Challenges in Reducing Losses from Natural Disasters" (adapted from an article in J. Ingleton (ed.), N*atural Disaster Management*, Leicester, UK: Tudor Rose, 1999, pp. 280–283). Online at http://www.usgs.gov/themes/sndr/sndr09.html (as of February 21, 2003).

National Science Board, *Science and Engineering Indicators 2002*, Arlington, VA: National Science Foundation, 2002. Online at www.nsf.gov/sbe/srs/seind00/start.htm (as of February 20, 2003).

National Science Foundation, Division of Science Resources Statistics, *Federal R&D Funding by Budget Function: Fiscal Years 2001–03*, Arlington, VA: National Science Foundation, NSF 02-330, 2002. Online at http://www.nsf.gov/sbe/srs/nsf02330/htmstart.htm (as of February 10, 2003).

Nigg, Joanne, "Predicting Earthquakes: Science, Pseudoscience, and Public Policy Paradox," in D. Sarewitz, R. A. Pielke, Jr., and R. Byerly, Jr. (eds.), *Prediction: Science, Decision Making, and the Future of Nature*, Washington, DC: Island Press, 2000, pp. 135–156.

Office of Management and Budget, "Instructions for Preparation and Submission of Budget Estimates," *OMB Circular A-11*, Washington, DC: U.S. Government Printing Office, June 1996.

Office of Science and Technology Policy, "FY 2002 Budget Summary with Tables," Washington, DC: Office of Science and Technology Policy, 2002. Online at http://www. ostp.gov/html/01_4_9.html.

Petak, William J., and Shirin Elahi, "The Northridge Earthquake, USA and Its Economic and Social Impacts," *Euroconference on Global Change and Catastrophe Risk Management: Earthquake Risks in Europe*, Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA), July 2000, pp. 1–28.

Pielke, R. A., Jr., "On Assessing Societal Exposure to Hurricanes," *Elements of Change,* Aspen Global Change Institute, 1996. Online at http://www.gcrio.org/ASPEN/science/eoc96/AGCIEOC96SSSI/AGCIEOC96Pielke.html (as of February 19, 2003).

_____, "Asking the Right Questions: Meteorological Research and Societal Needs," *Bulletin of the American Meteorological Society*, Vol. 78, No. 2, 1997, pp. 255–264.

_____, letter, *Science*, Vol. 284, May 14, 1999, p. 1123.

_____, and R. E. Carbone, "Weather Impacts, Forecasts, and Policy: An Integrated Perspective," *Bulletin of the American Meteorological Society*, Vol. 83, 2002, pp. 393–403.

Popper, Steven W., *Policy Perspectives on Measuring the Economic and Social Benefits of Fundamental Science*, Santa Monica, CA: RAND, MR-1130-STPI, 1999.

Stern, Paul C., and William E. Easterling (eds.), *Making Climate Forecasts Matter*, Panel on the Human Dimensions of Seasonal-to-Interannual Climate Variability, Washington, DC: National Academy Press, 1999.

Stokes, Donald E., *Pasteur's Quadrant: Basic Science and Technological Innovation*, Washington, DC: Brookings Institution Press, 1997.

Sykes, Lynn R., "Intermediate and Long-Term Earthquake Prediction," *Proceedings from the National Academy of Science*, Colloquium Paper, Vol. 93, No. 9, April 1996, pp. 3732–3739.

United States Congress, Office of Technology Assessment, *Reducing Earthquake Losses*, Washington, DC: U.S. Government Printing Office, OTA-ETI-623, 1995.

United States Geological Survey, Earthquake Hazards Program, "Earthquake Facts and Statistics." Online at http://neic.usgs.gov/neis/eqlists/eqstats.html (as of February 10, 2003).

Wagner, Caroline S., *International Cooperation in Research and Development: An Inventory of U.S. Government Spending and a Framework for Measuring Benefits*, Santa Monica, CA: RAND, MR-900-OSTP, 1998. Online at http://www.rand.org/publications/MR/MR900/ (as of March 10, 2003).

Ward, Sandy, and Catherine Main, "Reducing the Impacts of Coastal Hazards," *National Oceanic and Atmospheric Administration's State of the Coast Report*, Silver Spring, MD: National Oceanic and Atmospheric Administration, 1998. Online at http://state_of_coast.noaa.gov/bulletins/html/rtt_06/rtt.html (as of February 10, 2003).

White, Gilbert F., *Human Adjustment to Floods*, Chicago, IL: University of Chicago Press, 1945, pp. 1–2, 205–212.

Wilks, Daniel S., "Forecast Value: Prescriptive Decision Studies," in R. W. Katz and A. H. Murphy (eds.), *Economic Value of Weather and Climate Forecasts*, Cambridge, UK: Cambridge University Press, 1997.