by Walter W. Hays

Hazard and Risk Assessments in the United States

Every State and Territory in the United States has communities that are at risk from one or more of the natural hazards: earthquakes, volcanic eruptions, severe storms (hurricanes and tornadoes), floods, landslides, wildfires, tsunamis, and drought. During the 1990's, a period designated by the United Nations as the International Decade for Natural Disaster Reduction (IDNDR), the United States plans to marshal its intellectual, economic, and political resources to reduce loss of life, human suffering, and economic loss from these natural hazards. Hazard and risk assessments will be an important element of the United States' program. Such assessments are needed for the Nation's earthquake-prone zones, active volcanoes, thousands of miles of hurricane-prone coastline, large and small flood-producing drainage systems, slopes susceptible to landslides, regions prone to tornadoes, coasts susceptible to tsunami runup and storm surge, wilderness/urban interfaces vulnerable to wildfires, and regions subject to drought episodes. The goal is to provide a sound scientific and technical basis for predictions and warnings, preparedness, and mitigation measures so that communities can make themselves less susceptible to disasters. This paper describes the basic characteristics of the atmospheric, hydrologic, and geologic natural hazards the United States will face during the 1990's and its plans for reducing their impacts.

Introduction

The United States is planning a balanced and comprehensive program (fig. 1) of research and applications in the 1990's as part of the United Nations IDNDR. The U.S. program will be designed to reduce losses from natural disasters that are increasing rapidly due to population growth, urbanizations, and the concentration of industry and infrastructure in areas prone to recurrent natural hazards. The U.S. program will complement the programs of 154 other nations that joined in December 1989, with the U.S. in the 44th General Assembly of the United Nations to sponsor a resolution calling for all nations to develop programs to achieve the goals of the IDNDR to reduce loss of life, economic loss, and human suffering from natural disasters (United Nations, 1989).

The IDNDR is both an unprecedented opportunity and a challenge. The opportunity is to use planet Earth as a laboratory and the

Figure 1.—The US program for the International Decade for Natural Disaster Reduction will focus on research to increase the knowledge base on natural hazards and applications to reduce future losses from them. New initiatives are being devised to deepen the knowledge on specific subjects and to demonstrate the utility of various applications.

interactions of hazardous natural events with society as the experiments to deepen our understanding of the physical and social aspects of natural disaster reduction. The challenge comes from the fact that such a multidisciplinary effort has never been undertaken on a global scale for individual natural hazards, let alone multiple hazards.

The dimensions of the challenge of the IDNDR are shown by statistics compiled in 1989 by the United Nations International Ad Hoc Group of Experts. These suggest that planet Earth will experience many natural hazards during the decade of the 1990's:

- a million thunderstorms
- one hundred thousand floods
- tens of thousands of landslides, damaging earthquakes, wildfires, and tornadoes
- several hundred to several thousand tropical cyclones and hurricanes, tsunamis, drought episodes, and volcanic eruptions.

In the U.S., some of these recurrent natural hazards will cause a disaster, a disruption of the human ecology that exceeds the capacity of the community to function normally. The consequences of such disasters are grave as evidenced recently by floods in Arkansas, Texas, Ohio, and Washington; tornadoes in New York, Alabama, Indiana, and Illinois; wildfires in California and Wyoming; earthquakes in California; hurricanes along the Gulf and Atlantic coasts; volcanic eruptions in Hawaii and Alaska; and drought in the Midwest and California. At present, average annual losses reach \$20 billion.

Two disasters in 1989, Hurricane Hugo (U.S. Weather Service, 1990) and the Loma Prieta earthquake (State of California, 1990), are

examples of the devastating effects that a class 4 hurricane and magnitude 7.1 earthquake can have on the east and west coasts and on the Nation. Together, they caused direct losses of approximately \$15 billion, indirect losses of \$30–45 billion, killed 90 people, injured several thousand, and rendered tens of thousands homeless or jobless. These losses left a populace facing the rigors of a long, complex recovery process. Prediction and warning kept the loss of life low in Hugo, whereas mitigation measures and emergency preparedness kept it low for the Loma Prieta earthquake.

Characteristics of hazards in the United States

Hazard and risk assessments are the starting points for defining actions that communities can take to reduce economic loss, human impacts, and loss of life and injuries from natural hazards. Such assessments are used by communities to improve their capabilities in mitigation, prediction and warning, emergency response, and disaster recovery (fig. 2).

Mitigation and preparedness measures are initiated well in advance of a hazardous event in order to construct hazard-resistant structures and to deal with the requirements of emergency managers and the populace during the emergency response and the recovery periods. Mitigation measures (for example, building codes) have a goal of lessening damage to the physical development, loss of life, and societal disruption. Prediction and warning systems are designed to provide all sectors of the population with information on the location, birth and development, severity, onset time, and duration of an impending hazardous event so that they can evacuate or take actions to lessen or suppress the anticipated effects.

Hazard Assessment

Hazard assessments involve two activities: (1) characterization of the physical phenomena triggered by a natural hazard on temporal and spatial scales and (2) presentation of the physical effects in a map format that community decisionmakers and practitioners can use to adopt and enforce emergency preparedness and mitigation measures and to develop a predictive capability. Characterization of the physical phenomena is difficult because each type of natural hazard varies from region to region in its mode and frequency of occurrence, and each natural hazard generates a unique ensemble of physical effects that affect the built environment in different ways.

The following questions are typical in hazard assessments:

- Where have natural hazards happened in the past?
- How severe were the levels of physical effects (for example, wind velocity, storm surge, or ground shaking) triggered in past events?
- What levels are expected to be triggered in future events?
- How frequently, on the average, do events capable of generating severe physical effects occur?

Hazard assessments are based on the knowledge base developed through past research and on each natural hazard (Hays, 1981; National Research Council, 1987). These studies have shown that natural hazards, such as hurricanes, earthquakes, volcanic eruptions, and drought, involve physical processes that develop on a global scale, but that are assessed on regional and local scales. To monitor their birth and to track their spatial and temporal development require sophisticated monitoring systems that use satellites and remote sensing instruments capable of detecting small changes in the causative physical parameters of the geologic, meteorological, and hydrological systems. The other natural hazards—landslides, floods, torna-

IMPLEMENTATION OF LOSS-REDUCTION MEASURES

Figure 2.—Communities throughout the Nation are able to choose the types of applications that are best for them to use for reducing their potential risk from natural hazards.

does, wildfires, and tsunamis—are just as complex; however, their causative mechanisms develop on regional or local scales instead of global scales.

Floods happen more frequently than any other natural hazard. They occur annually in every season of the year, causing direct losses of about \$4 billion per year. All States have communities that are at risk from flooding that is caused by heavy rainfall, often in association with thunderstorms, tornadoes, and hurricanes. Flash floods, the most dangerous, are hard to forecast. Riverine flooding in the more than 10 million km of the Nation's river systems is caused by heavy rainfall and rapid snowmelt. Storm surges generated seasonally in hurricanes inundate thousands of miles of vulnerable Gulf of Mexico and Atlantic coast. Urbanization, deforestation, wildfire, and other human and natural actions change drainage patterns, leading to floods.

Landslides also occur annually and impact every State and territory. Landslides are manifest as falls, topples, slides, spreads, and flows of rock and soil that are triggered by meteorological or seismological events. They can also be caused or exacerbated by denuding of hills or steep slopes. Landslides cause direct losses of about \$2 billion per year. California, Alaska, Washington, Utah, Kentucky, Tennessee, Ohio, West Virginia, Puerto Rico, and American Samoa have the most extensive and frequent problems.

Severe storms (hurricanes and tornadoes) and wildfires occur annually, but they are seasonal and more restricted geographically within the Nation than floods or landslides. Virtually every year, about a dozen hurricanes strike the Gulf and Atlantic coasts in late summer and autumn. Hurricanes can have wind velocities that reach 338 km/h, generate as much as 76 cm of rain in a few days, and produce a storm surge of up to 7.6 m in coastal areas. Hurricanes leave a broad path of destruction after they make landfall. Several hundred tornadoes strike the interior of the Nation annually. All States are at risk; however, they strike most frequently along "tornado alley" in Oklahoma, Texas, and Kansas. Their wind speeds can reach 480 km/h. They leave a broad path of destruction. Several hundred wildfires, or uncontrolled conflagrations, occur every year, mainly in the western States, especially during or after hot, dry summers. Lightning causes many wildfires, but others occur as a result of sparks from campfires, arson, and sometimes from earthquakes or lava flows.

The frequency of drought episodes, which depends on atmospheric conditions, can vary from once every several years to once every several decades. All regions of the Nation are vulnerable to drought. Past episodes of severe drought have highlighted the importance of continuous monitoring to provide early warning of impending water shortages, so that potential impacts can be assessed and response options developed and implemented in a timely manner.

Tsunamis are large ocean waves generated by a submarine earthquake, or sometimes by an underwater volcanic eruption. They can be very destructive at great distances from the source as well as near the source. They strike Hawaii more frequently than any other part of the Nation. However, Alaska, California, Washington, Oregon, Puerto Rico, and the Virgin Islands have also experienced tsunamis, sustaining damage from inundation, wave impacts on structures, and coastal erosion.

Earthquakes and volcanic eruptions, two of the most destructive natural hazards as single events, happen relatively infrequently in comparison to other natural hazards. Earthquakes, which can strike anywhere in the Nation, are most destructive near the source where they generate strong ground shaking and trigger permanent ground failure (for example, liquefaction and landslides). Unlike in the Western United States, where effects are limited to a portion of a State, damaging ground motion and ground failure effects can extend over several States in the East. Earthquakes can also cause damaging secondary effects such as flooding from dam failure, fire, and after-

ELEMENTS OF RISK

Figure 3.—Risk assessments require careful analysis of the spatial and temporal vulnerability of the structures exposed to natural hazards at various locations in a community.

shock sequences that can bring down damaged but noncollapsed buildings. Moderate-magnitude earthquakes (that is, magnitude 5.5 to 7.0), which can strike anywhere in the U.S., have recurrence intervals from every few years in California and Alaska to about once every 50 to 100 yr in the Central Mississippi Valley. Large- and great-magnitude earthquakes (that is, magnitudes ranging from 7 to greater than 8) occur about every 100 yr in Alaska and California and about once every 500 to 1,000 yr in Central Mississippi Valley area. Volcanic eruptions, which are restricted to the Western United States, are also very destructive near the source. They generate ash fall, lahars (that is, mud flows generated by melting of snow and ice), lava and pyroclastic flows, and lateral blasts. The frequency of small-volume eruptions is about once every century, and large-volume eruptions about once every 1,000 to 5,000 yr. Very large volume eruptions, which are rare, occurring only about once every 10,000 yr, can cause climate change. Parts of Alaska, Hawaii, Washington, Oregon, California, Nevada, Utah, Arizona, and New Mexico are at risk.

Risk Assessment

Risk assessments involve scientific, societal, and economic considerations. The main factors are: (a) the location of buildings, facilities, and lifeline systems within a community; (b) their exposure to the physical effects of a natural hazard; and (c) their vulnerability (that is, potential loss in value) when subjected to these physical effects (fig. 3). Risk is a statement of the economic losses, deaths and injuries, and loss of function expected when a specific physical effect (for example, ground shaking or severe winds, triggered by a natural hazard) strikes a given region, local jurisdiction, site, or structure. When the spatial and temporal characteristics of the physical effects are fully integrated with a community's inventory of buildings, facilities, and lifeline systems, the risk to the community can be determined. Realistic mitigation measures can be adopted and enforced through siting, design, and construction practices.

The following questions are typical in risk assessments:

- What kinds of damage will the physical effects of a natural hazard cause to buildings, facilities, and lifeline systems that are at risk in a community?
- What have communities done in the past to control damage, deaths, injuries, economic loss, and loss of function from these effects?
- What societal, scientific, and technical actions will reduce the vulnerability of existing buildings and lifeline systems in each community to future events?

Loss estimates have been made in selected communities for scenario events of most natural hazards. These estimates have shown that two individual events, earthquakes and hurricanes, are capable of causing catastrophic losses, potentially reaching \$100 billion or more in a single event (National Research Council, 1987). Such assessments have also exposed gaps in knowledge on spatial (for example, urban to site-specific) and temporal (for example, 10- to 100-yr) scales. In spite of gaps in knowledge, such loss estimates are useful for a community. They can be used to identify especially hazardous geographic areas, groups of buildings, or lifelines; to aid in the development of emergency response plans; to evaluate overall economic impact on the Nation; and to formulate general strategies for earthquake risk reduction such as land use plans or building codes.

Prediction and Warning

A prediction is based on science and depends on continuous monitoring in space and time of the causative mechanisms that are capable of generating a hazardous event. It is a neutral statement that indicates that accumulated observations of the physical phenomena signal the eminent occurrence of a hazardous event (National Academy of Sciences, 1975). A warning is an interpretation of a prediction that takes public policy into account (National Academy of Sciences, 1975). It is a public declaration that the normal routines of life should be altered for a period of time to deal with the danger posed by the imminent event. Warnings depend heavily on timeliness, public information systems, and credible sources for their success.

Two basic questions are at the heart of the science for predicting the time, place, and severity of natural hazards. They are: (1) Why does a specific natural hazard occur? and (2) When it does occur, what will happen?

The answers to both questions involve the detection, measurement, and evaluation of changes in the physical environment. The answer to the first question, "why," can be formulated from the answers to a series of interrelated questions that address the three critical elements of a prediction and warning; that is, "where," "when," and "how severe." The answer to the second question, "what will happen," forms the essence of the warning that is communicated to the populace at risk. This message should be designed to provide the threatened population with information about the threat and what can be done to prevent, avoid, or minimize it.

Prediction and warning for hurricanes and earthquakes illustrate the full range of technical and societal problems. Much shorter warning times are currently possible for hurricanes than for earthquakes. For hurricanes, the elapsed time between a prediction, the warning, and the occurrence of the disaster consists of days, hours, and minutes; whereas, it is presently decades and years for earthquakes. Hopefully, in the near future, the capability to predict and warn in terms of days, hours, and minutes will be achieved for earthquakes. Unlike a hurricane, earthquakes are not preceded by clearly discernible signs that the public can confirm with their own senses. This fact makes earthquake prediction and warning unique. At present, public response depends on the faith people have in the

science of earthquake prediction and in the scientists and public officials issuing the warning.

Prediction and warning gives a community a greater number of options for reducing the potential danger. A long lead time provides the opportunity to evacuate and relocate people, to strengthen buildings, to reduce density of occupancy, and to correct structural and nonstructural vulnerabilities. Even a relatively short advance notice gives adequate time to take steps to protect life.

Hurricane Hugo and the Loma Prieta earthquake illustrate the value to society of good prediction and warning systems. Hurricane Hugo was identified, predicted, and tracked continuously by the National Weather Service from its birth in the Atlantic Ocean, to its sweep through the U.S. Virgin Islands and Puerto Rico, to its landfall at 12:20 a.m. on Friday, September 22, 1989, 10 miles north of Charleston, South Carolina, and its eventual decay to a storm category (fig. 4). These warnings were based on weather observation networks that included satellites, Doppler radars, and automated surface networks of meteorological and hydrological stations. Only 28 people from the Caribbean to the United States were killed because of effective evacuation procedures, which were implemented on the basis of the short-term real-time warnings. In contrast, the Loma Prieta earthquake struck Northern California without warning at 5:04 p.m. on Tuesday, October 17, 1989. Only its location in the Santa Cruz mountains and its size had been predicted in 1988 (fig. 5) (that is, a 30 year forecast) (U.S. Geological Survey, 1988 and 1990) on the basis of the concept of the seismic cycle. This concept holds that earthquakes occur when steadily increasing shear stress exceeds the strength of the rocks on a fault in a region and repeat in a similar manner when stress increases again to that same failure level. The Loma Prieta earthquake caused property damage of \$5.6 billion, 62 deaths, 3,757 injuries, and left 8,000 people homeless.

TWO PATHS: PREDICTED AND ACTUAL HURRICANE HUGO September 22, 1989

Figure 4.—Comparison of the actual and predicted paths of hurricane Hugo, September 22, 1989.

GAPS IN SEISMICITY

1/69–8/89

LOMA PRIETA EARTHQUAKE AND AFTERSHOCKS

Figure 5.—The Loma Prieta earthquake of October 17, 1989, filled a seismic gap on the San Andreas Fault that had been recognized in 1988.

U.S. program for the IDNDR

The U.S. Decade program has been prepared through the separate but complimentary efforts of a 17-member national committee convened in 1989 by the National Academy of Sciences' National Research Council (NRC) and the Federal science and disaster-reduction agencies, the latter group working as the Subcommittee on Natural Disaster Reduction (SNDR). The SNDR is part of the Federal Coordinating Council on Science and Engineering's Committee On Earth Science that reports to the President's Office of Science and Technology. These efforts led to recommendations for the public and private sectors to work together to marshal the Nation's intellectual, economic, and political resources so that all parts of the Nation will be more resilient from natural hazards by the beginning of the 21st century (Hays, 1990).

The U.S. Decade program will call for action at the local and State level and involve as many as 30,000 local jurisdictions and several million people. The state of knowledge and state of preparation for natural hazards varies widely in each jurisdiction. Each local jurisdiction will be encouraged to adopt and enforce policies that will reduce losses from natural hazards through implementation of a balanced program of science and technology and applications (see fig. 1). Scientific and technological research will develop a deeper understanding of (1) the physical and biological processes that cause natural hazards; (2) the technological capabilities that society is able to marshal to mitigate the physical effects of natural hazards; and (3) the characteristics of the human interaction system that enable society to prepare for, respond to, and recover from natural disasters.

The applications component will be designed to strengthen the capability of communities located in hazard-prone regions throughout

the Nation to reduce the potential for disaster. The potential for disaster exists because communities are located in or adjacent to fault zones capable of generating damaging earthquakes, along coasts where hurricanes, storm surges or tsunami flood waves strike, near active volcanoes, on unstable slopes susceptible to landslides, in floodplains subject to inundation, in regions prone to tornadoes, along wilderness/urban interfaces vulnerable to wildfires, and in regions subject to drought episodes or insect infestation.

Moreover, the Nation's inventory of building wealth is growing at a rate of \$400 billion per year as new public and private construction adds buildings and lifeline systems. The total value of new construction that will be added to the Nation's inventory during the 1990's will reach approximately \$4 trillion. These applications will enable individual communities to meet their needs for:

- Preparation—knowledge of how to prepare for a natural disaster.
- Prediction—knowledge of how to predict the occurrence and consequences of potentially hazardous events, and to warn the populace at risk.
- Intervention—knowledge of how to evacuate and intervene while a natural hazard is in progress and to suppress its physical effects.
- Recovery—knowledge of how to restore the essential community functions to normal and to correct deficiencies in preparation.
- Emergency Assistance—knowledge of how to provide effective emergency assistance, including search and rescue, immediately after the event strikes a community.

The U.S. program involves specialists in many disciplines and will consist of a wide variety of projects. They will include hazard and risk assessments; preparedness and mitigation measures; prediction and warnings for all natural hazards; planning, siting, design, and construction practices; awareness and education for all sectors of

the society; loss reduction based on lessons learned from disasters throughout the world; and cooperative national and international endeavors designed to collect, analyze, and share data, experiences, and mitigation techniques for specific natural hazards.

Three demonstration studies are envisioned. They will serve as integrating mechanisms for each local jurisdiction in the United States who participate in the program. They are:

- Disaster Prevention Resource Network—Development of a national multihazards information system that can be used to solve local and national needs for natural disaster data.
- Natural Hazard Predictions—Use of specific hazard-prone locations as “natural laboratories” to advance the capability to predict each type of natural hazard that local jurisdictions are exposed to and to warn the people.
- Disaster-Free Regions—Cooperative efforts by local jurisdictions in selected geographic regions who elect to devise and undertake specific actions to make the jurisdiction and the region “disaster-free.” For example, local jurisdictions may choose to establish disaster-free schools and hospitals and other essential facilities.

The progress of each local jurisdiction will be monitored as the U.S. Decade program unfolds. Each local jurisdiction has the constitutional right to choose some, all, or none of the proposed elements of the U.S. Decade program. Many qualitative changes can be measured as indices of accomplishment. The number of publications, maps, and products that deepen understanding of the physical and social aspects of natural disaster reduction will be a key indicator of accomplishment. Our school children's knowledge of natural hazards and what to do when they occur can be compared with that of their counterparts in other countries at various intervals during the 1990's. The number of local jurisdictions that adopt and enforce a mitigation policy can be measured in terms of the number that improve their hazard and risk assessments and exercise their emergency response and recovery plans or pass legislation to strengthen the enforcement of building regulations and land use plans or strengthen unsafe schools and hospitals. The number of individuals in each local jurisdiction who are trained in disaster preparedness and mitigation measures will demonstrate the level of direct local participation. Beliefs and behavior patterns of the mass media, citizens, scientists, engineers, emergency managers, and policymakers as represented by their professional practices and standardization of vocabulary, together with the numbers of researchers and practitioners who work together on multidisciplinary projects, as well as improvements in professional practices to accommodate the lessons that are learned from postdisaster investigation will show the level of societal, scientific, and technical awareness and accomplishment. Bilateral and multilateral international cooperative projects will indicate the level of international political resolve.

Some activities involving long-term changes in professional practices of planning, siting, design, and construction should also be measured, but they will require a longer monitoring period than the 1990's. An example is that the effectiveness of the adoption and enforcement of the new wind and seismic design provisions of building codes in South Carolina, Tennessee, or New York will be harder to evaluate during the 1990's.

The ultimate measure, however, is to determine if the number, frequency, and severity of natural disasters in the United States decreases in the 21st century as a consequence of actions implemented during the 1990's.

Summary

The United States has accepted the challenge of the IDNDR because every State and Territory has communities that are at risk from one or

more of the natural hazards that recur at intervals, ranging from every year for floods, landslides, tornadoes, hurricanes, and wildfires to once every few years for damaging earthquakes in California and drought episodes in various regions of the Nation and once every century or more for major earthquakes in Alaska, California, and the Mississippi Valley area; large volcanic eruptions in the Pacific Northwest and Alaska; and drought in the Midwest and California. By increasing the knowledge base and accelerating applications, every community in the Nation can reduce its risk to natural hazards, making the Nation more resilient to natural disasters.

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