UNITED STATES
DEPARTMENT OF THE INTERIOR
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A Report of the Interagency Coordinating Committee's Subcommittee on Postearthquake Investigations

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THE NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM (NEHRP): POSTEARTHQUAKE INVESTIGATIONS

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ABSTRACT

The National Earthquake Hazards Reduction Reauthorization Act of November 16, 1990 requried the NEHRP agencies to organize a program of postearthquake investigations that would take advantage of the opportunity to use worldwide damaging earthquakes as a scientific laboratory.

INTRODUCTION

This report describes the current program of postearthquake investigations after damaging U.S. and foreign earthquakes conducted under the auspices of the National Earthquake Hazards Reduction Reauthorization Act of November 16, 1990 (Public Law 101-614). This Act established within USGS responsibility to organize a comprehensive and integrated postearthquake investigations program and required FEMA to prepare a report which examines the possible options for funding these investigations. A Working Group on Postearthquake Investigations was established in1991 with concurrence of the Interagency Coordinating Committee to prepare this report.

This report is a description of NEHRP postearthquake investigations which can be used for planning future activities. It establishes objectives, but leaves open the interactive interdisciplinary process for achieving them. It describes the range of studies that are needed and identifies the most likely

contributing organizations, but leaves open the identity of those who will perform the studies and the details on how they will be accomplished. The emphasis is on inclusive rather than exclusive participation and on creativity rather than fixed procedures.

The goal of NEHRP postearthquake investigations is to document, understand, and explain what happened in each damaging earthquake in order to reduce losses from future earthquakes. To achieve this goal, investigations are designed to study parameters of the three interrelated systems which together represent the full range of society's exposure to earthquakes. The individual systems are:

1. the solid earth system, which generates the earthquake phenomena that threaten the built environment of the community,

2. the built environment system, which houses, services, and sustains communities exposed to the potentially destructive impacts of earthquake phenomena, and

3. the social-economic-political system of a community, which adopts and enforces earthquake risk management policies and practices in the community to withstand and recover from earthquake phenomena.

All four NEHRP agencies (USGS, FEMA, NSF, and NIST) have roles in conducting or supporting postearthquake investigations. Two others, CDC and OFDA, also contribute.

POSTEARTHQUAKE INVESTIGATIONS OF EARTHQUAKE HAZARDS

The physical effects (i.e., earthquake hazards) damage or destroy buildings and lifeline systems (e.g., bridges, dams, pipelines, utility systems, tunnels, rapid transit) in urban centers and cause socioeconomic impacts over broad geographic regions. Within a minute or less economic losses can reach several tens of billions of dollars. Ground shaking can trigger liquefaction (i.e., a temporary loss of bearing strength at locations underlain by young, loosely compacted, water-saturated sand deposits) and landslides (i.e., falls, topples, slides, spreads, and flows of rock and/or soil on unstable slopes). Some earthquakes will also generate surface fault rupture where, depending on the magnitude or amount of mechanical energy released at the initial rupture zone, the fault can propagate upward, and break the surface. Surface fault rupture, liquefaction, and landsliding cause permanent displacements, which can be especially damaging to underground lifeline systems. Regional tectonic deformation (i.e., changes in elevation over a broad geographic region) is a characteristic of great-magnitude earthquakes (i.e., those having magnitudes of 8 or greater). Tsunamis (i.e., long-period ocean waves generated by the sudden vertical displacement of a submarine earthquake) can generate flood waves that can destroy ports and harbors and buildings at coastal locations far from and close to the earthquake source. Seiches (standing waves induced in lakes and harbors), dam failures, and fires can

also be induced by an earthquake. Aftershocks (i.e., smaller magnitude earthquakes, following the main shock) can occur for several months to years, repeating and worsening the physical effects described above, depending on their magnitude, proximity to the urban center building or lifeline or site, and the incipient damage state of the remaining structures. NEHRP postearthquake investigations seek to understand and quantify these physical efffects in order to develop the best possible loss reduction measures. The knowledge gained from investigations provides a basis for determining the best ways to prevent future losses.

STRATEGY AND PRIORITIES FOR CONDUCTING NEHRP POSTEARTHQUAKE INVESTIGATIONS

Past Experiences

In the past, NEHRP postearthquake investigations have been able to access up to $5 million of NEHRP agency funds. Funds from ongoing programs of USGS, NSF, and NIST have been redirected to conduct field work in the stricken region, perform reconnaissance studies throughout a broader geographic area, and support research studies to integrate all of the data in order to learn from the earthquake. NEHRP postearthquake investigation costs are directly related to the duration of the field work and reconnaissance studies and the scope and complexity of the research studies; the costs increase as the size (magnitude) and destructiveness of the earthquake increase. In addition the costs for foreign field work, reconnaissance studies, and research (if any) are unlikely to be reimbursed by the host country.

The NEHRP objectives of postearthquake investigations are to (Figure 1):

1. Assemble and set priorities on previously identified problems and research needs that can be addressed by investigating one or more future domestic or foreign earthquakes.

2. Acquire and analyze time sensitive or perishable data and other important information in order to establish a knowledge base and to learn as much as possible from the physical and societal aspects of the tragedy which cannot be duplicated in the class room, on a shaking table in the laboratory, by computer, or in scenarios and exercises.

3. Use the opportunity provided by the earthquake to accelerate the acquisition of fundamental knowledge on the earth science, engineering (including casualty studies), and social science aspects of earthquake risk management (i.e., prevention, mitigation, and preparedness measures).

4. Increase the awareness of policymakers and decision-makers on the earthquake hazard and their options for risk management.

5. Transfer technology to and from all regions of the Nation and other countries to increase the capacity of professionals to perform postearthquake

investigations and communities to implement earthquake risk management policies and practices.

6. Promote realistic change through scientifically based expansion and extension of earthquake risk management policies and practices throughout the Nation.

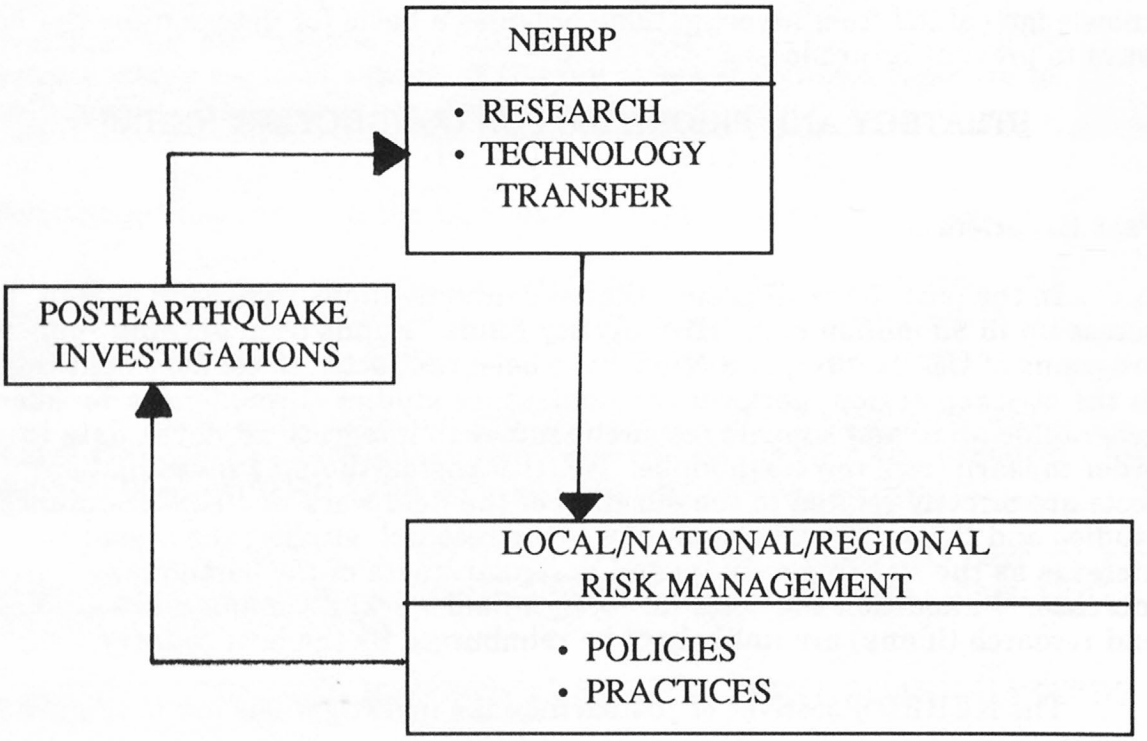

Figure1.--Objectives of NEHRP Postearthquake Investigations.

The current NEHRP program of postearthquake investigations is built on the procedures and successful experiences gained from past investigations of damaging earthquakes in the United States (e.g., 1989 Loma Prieta, CA; 1987 Whittier-Narrows, CA; 1983 Borah Peak, ID; 1983 Coalinga, CA; 1979 Imperial Valley, CA; 1971 San Fernando, CA; and 1964 Prince William Sound, AK) and abroad (e.g., 1993 Hokkaido-nansei-oki, Japan; 1992 Erzincan, Turkey; 1991 Costa Rica; 1990 Philippines; 1988 Spitak, Armenia; 1985 Mexico; 1985 Chile; 1980 Italy; 1980 Algeria; and 1976 Guatemala). The NEHRP agencies, CDC, and OFDA have all par ticipated in various ways in these investigations. CDC, based in Atlanta, Georgia, documents and quantifies the public health consequences of earthquakes in order to build a data base on earthquake casualties and to identify strategies which will prevent or mitigate the medical and public health consequences of earthquakes. OFDA's primary role is in international emergency relief and in facilitating investigations of foreign earthquakes by the NEHRP agencies and others.

The strategy is to take full advantage of the unique laboratory provided by a damaging earthquake in the United States or abroad. After a damaging earthquake, the initial focus will be on the stricken area. Teams of investigators, drawn from the professional staffs of USGS, NIST, and CDC and/or individual researchers, university consortia, or professional organizations supported by NSF, FEMA, and USGS conduct reconnaissance studies to define the limits of the region to be studied and the research opportunities.

Each NEHRP agency is responsible for initiating the postearthquake investigations and related activities in cooperation with each other and other cooperating organizations. Each agency, as well as CDC and OFDA, manage and fund their own investigations. They may make midcourse adjustments on the basis of the information received from coordination and communication with each other, the reports from the teams conducting field and reconnaissance studies, USGS's NEIC and other sources. The expectation is that individuals and organizations working together in the crisis environment will soon fill the most critical or priority gaps in the technology base.

Investigations of past damaging earthquakes not only have exposed gaps in the NEHRP technology base (i.e., the information, knowledge, and professional capacity that communities need for earthquake risk management), but they also have begun to fill some of the gaps. At present, three categories of studies are performed in every postearthquake investigation to build a technology base. Each one is described below in terms of the professional disciplines involved. The current critical or priority gaps in the technology base are also identified in general terms.

Earth Science Investigations - (Lead Federal Agencies: USGS and NSF. Others: State Geological Surveys, universities, university consortia (e.g., IRIS, UNAVCO), professional organizations, the private sector, etc.).

Geologic Studies - These studies use a wide variety of techniques such as overflights, satellite observations, geodynamic measurements, and field mapping to accomplish the goals which encompass: 1) understanding ground shaking, crustal deformation, and ground failure; 2) defining the regional seismotectonic setting; and 3) mapping, assessing, and analyzing **faulting phenomena**, the geometry and physical properties of **soil deposits** and bedrock, **regional tectonic deformation, liquefaction, landslides**, and **flood-wave inundation**.

Priorities of Geologic Studies - Highest priority is given to those studies which help to understand on local and regional scales the influence of local and regional earth structure on individual earthquake phenomena and on a global scale the physics of tectonic forces. Specific priorities vary as a function of its location, physical characteristics, and societal impacts of each damaging earthquake. The NEHRP goal is to attain the capability to predict the location, time, and size of future earthquakes and the temporal and spatial characteristics of their phenomena on the basis of geologic data.

Seismological Studies - These studies use a variety of techniques such as fixed local, regional, national, and global seismometer networks and portable instrument arrays to characterize and understand the **main shock and aftershock sequence**. Arrays of portable seismographs are used to locate aftershocks in the epicentral region, determine their spatial and temporal characteristics, define the rupture zone, relate the main shock to the long-term regional seismicity, and explain **precursory geophysical phenomena**, if any, before the main shock.

Priorities of Seismological Studies - Highest priority is given to those studies which help to understand on a local, regional, and global scale the geophysical and geologic phenomena that occurred and that might be expected to occur again in future earthquakes so that their occurrence and source parameters can be predicted in terms of geophysical parameters. Specific priorities will vary with each damaging earthquake. The NEHRP goal is to attain the capability to predict the occurrence and consequences of future earthquakes on the basis of seismological data.

Engineering Seismology Studies - These studies use techniques such as permanent local and regional strong-motion instrument arrays and portable strong motion instruments to acquire quantitative data (i.e., strong motion accelerograms and spectra, pore water pressure measurements, etc.). These data are used to improve understanding of regional **seismic wave propagation** and local **ground response** and **ground failure** and to relate ground motion effects from both the aftershocks, the main shock, and past earthquakes to parameters of the solid earth system. Strong motion accelerograms and spectra derived from them are used to guide earthquake resistant design.

Priorities of Engineering Seismology Studies - Highest priority is given to those studies which help to understand the physical characteristics of local and regional ground motions and to predict their amplitude, frequency composition, and duration in terms of source, path, and site parameters of the solid earth system along with estimates of uncertainty and variability. Specific priorities will vary with each damaging earthquake. The NEHRP goal is to attain the capability for reliable predictions of regional and local ground motions for use in loss estimation scenarios and siting, design, and construction applications.

Engineering Investigations - (Lead Federal Agencies: NSF, NIST, CDC, and USGS. Others: The ICSSC, professional organizations (e.g., EERI, NAS/NRC, universities, university consortia (e.g., NCEER), the private sector (e.g., consulting engineers and architects, the building trades, and insurance companies), and others).

Engineering Studies - These studies currently use a variety of qualitative (e.g., photos and slides) and quantitative (e.g., accelerograph records and material testing) techniques to ascertain the nature, cause, degree, and spatial distribution of **damage** to a wide variety of **structures** and **foundations** in the

stricken community. Technical assistance may also be required after the earthquake to assess the safety of buildings (e.g., to assign "red, yellow, and green" tags to buildings after the earthquake to signify "unsafe," "use caution," and "safe to use"). The structures include: **dwellings, low-, medium-,** and **high-rise buildings**, and **industrial facilities; lifelines** (i.e., those systems that transport people, distribute resources, and transmit information), **essential facilities** (e.g., schools, hospitals, emergency operations centers), and **critical facilities** (i.e., dams, nuclear power plants)). This information is used to develop and refine architectural, geotechnical and structural engineering, and land-use planning principles and practices. Vulnerability relations are derived in order to refine or revise building and lifeline regulations; improve siting, design, and construction criteria; and advance professional practices.

Priorities of Engineering Studies - Highest priority is given to those studies in the stricken community which help to understand and predict the physical, human, and economic consequences of ground motion and ground failure on buildings and lifelines and to devise methods for improving their performance under the range of dynamic earthquake loads expected to occur during their useful life. Specific priorities will vary as a function of the destructiveness and damage distribution in a given earthquake. The NEHRP goal is to protect property through earthquake-resistant design of buildings and lifelines and people in each earthquake-prone region of the Nation.

Casualty Studies - These studies use site-specific determinations of casualties and building damage in the stricken area to correlate deaths and injuries with building type, local geology, and land use and building regulations in the community. These data provide a basis for improving search and rescue efforts, planning emergency health care, developing reliable methodologies for estimating deaths and injuries, and improving design and construction methods to reduce casualties.

Priorities of Casualty Studies - Highest priority is given to those studies in the stricken area which help to quantify the potential health care needs of the occupants of buildings that may collapse or sustain severe damage in future earthquakes. Specific priorities will vary as a function of the destructiveness of the earthquake and the number of dead, injured, and trapped occupants. The NEHRP goal is to reduce casualties.

Social Science Studies - (Lead Federal Agencies: NSF and FEMA Others: NAS/NRC, universities, the private sector, etc.)

Societal Response Studies - These studies use field work and quantitative and qualitative techniques such as interviews to determine how the populace and government organizations in the stricken area and the region used **earthquake hazards and risk information** and **predictions and warnings**, if any, **before , during**, and **after** the earthquake. Databases can also be developed to show the distribution of economic losses, the factors that lead communities to make decisions about their earthquake risk management, and

the degree to which planning for response or recovery has been able to address foreseeable and unforeseeable consequences.

Priorities of Societal Response Studies - Highest priority is given to those studies in the stricken area and the region which help to understand how and why individuals, families, organizations, and communities adopt and enforce earthquake risk management policies and practices to reduce potential future societal and economic impacts. Specific priorities will vary as a function of the overall social, economic, and political factors in the stricken community. The NEHRP goal is to foster the adoption and enforcement of realistic earthquake risk management policies and practices throughout the Nation.

ORGANIZATION FOR IMPROVING NEHRP POSTEARTHQUAKE INVESTIGATIONS

Coordination

NEHRP agencies are responsible for initiating and funding their postearthquake-investigation activities and contributing to the coordination process. Coordination will be achieved under the ICC. Collectively, the NEHRP agencies will have access to the results of the earth science, engineering, casualty, and social science investigations conducted by the staffs of USGS, NIST, and CDC or by EERI, IRIS, UNAVCO, University of Colorado, NCEER, SCEC, NAS/NRC, and others through NEHRP agency grants.

Formation of Subcommittee on Postearthquake Investigations

A standing subcommittee on postearthquake investigations is needed to identify gaps in the technology base (i.e., information, knowledge, and capacity) and to facilitate coordination. Some of the rationale for establishing such a subcommittee of ICC and its broad charge are described below:

At present, NEHRP postearthquake investigations are still in the discovery and integration phases in all regions of the Nation, including California. In California, the integration of earth science, engineering, and social science data and knowledge and the development of capacity are advanced in some communities, but they lag in many others. The working group believes that

1. There are significant gaps in the technology base which future postearthquake investigations can fill.

2. Even after postearthquake investigations of damaging earthquakes, gaps may still exist, partially as a function of the funds available to collect and analyze perishable data or the lack of professional capacity to perform state-of-the-art studies.

3. The potential of the next damaging domestic or foreign earthquake to fill the identified gaps cannot be fully predetermined. More often than not, it is not immediately apparent until after the initial field work and reconnaissance

studies are completed what the best opportunities were; then it may be too late to collect some of the required perishable or time sensitive data to fill them.

4. While in the discovery and integration phases, the priorities of future postearthquake investigations should be driven by NEHRP goals.

The Working Group believes that a standing subcommittee on postearthquake investigations can significantly contribute to ongoing NEHRP postearthquake investigations. Its mission would be to:

1. identify the major "knowledge gaps" or capacity needs which should be filled in future postearthquake investigations;

2. identify the knowledge, data, and capacity needs of NEHRP in connection with the identified "gaps";

3. assesses, after each damaging earthquake, the extent to which that earthquake filled the gaps;

4. identify the common data that should be collected from each damaging earthquake to create the databases needed for specific risk management applications; and

5. direct the dissemination of the new data and analyses to the appropriate sectors of the public so that the most effective use will be made of these data and analyses to achieve NEHRP goals.

Some of the principal procedural and administrative points that shall apply to the subcommittee are outlined below:

Each NEHRP agency will have up to two representatives on the subcommittee;

The chair of the subcommittee, presently filled by USGS, shall be agreed to by subcommittee members;

Other Federal agencies such as CDC and OFDA may be invited to serve on the subcommittee;

The subcommittee shall meet as often as necessary, but not less than twice per year;

The subcommittee shall communicate or meet as soon as practicable within the first 48 hours after a damaging earthquake;

The subcommittee shall recommend specific priorities for future postearthquake investigations, either before or after future events and inform the ICC of such recommendations;

The subcommittee may recommend expenditures of funds from the NEHRP postearthquake investigations fund, which FEMA shall administer, to accomplish specific objectives.

Examples of Gaps in the NEHRP Technology Base

The current literature (see references) identifies a number of gaps in the present NEHRP technology base. Four examples are discussed below: 1) instrumentation for earth science investigations, 2) documentation, 3) increased capacity for engineering investigations, and 4) casualty estimation.

Instrumentation for Earth Science Investigations

At present, an urgent need exists for organizations to work out a priority scheme for multiple usage of the available equipment (e.g., GPS, strain and tilt meters, portable seismometers, and portable strong motion accelerographs. Without scientific instruments, important scientific and emergency response questions about the spatial and temporal variation of earthquake phenomena cannot be answered quantitatively. Although the number and quality of various types of modern instruments have grown with time and modern instruments are now deployed in long-term monitoring and research programs in many earthquake prone regions, a damaging earthquake can create a special need for coordination because of competition for the same sometimes limited inventory of equipment. To ensure that the needs of measurement programs in future earth science investigations are met, organizations should be prepared in advance of a damaging earthquake to remove instruments temporarily from existing fixed networks and to loan or share them and the data with other organizations. Otherwise, rare opportunities to collect important data may be missed.

Documentation

At present, NEHRP postearthquake studies have been deficient in obtaining a complete set of quantitative information following the reconnaissance efforts. Such documentation--which applies to all the disciplinary areas--customarily takes from 1 to 3 months and is often labor intensive. Typical information needed includes data on a) building damage and performance, b) individual and community actions and response, and c) earth science information of many types. The main reason for the gap is that such data gathering goes beyond the capability and present mission of the typical 1-to-2-week effort by a volunteer reconnaissance team. Much of this work could be done by graduate students or junior practitioners under proper supervision. If the documentation is provided, important databases will be completed. The need is for an organized NEHRP effort to provide the documentary data discussed above.

Increased Capacity for Engineering Investigations

There continue to be major gaps in the quantitative data base concerning the behavior of buildings, components of lifelines and land forms.

One major example is the need for statistical information on the number of damaged and undamaged buildings of various types concerning the extent of damage to lifelines, etc. Careful, meticulous documentation is necessary to ensure that meaningful data are obtained.

Individual buildings, structures, lifeline components, and land forms--both those with damage and those undamaged--can provide quantitative information of great value. When a member of a reconnaissance team stands in front of a damaged structure, she or he should be asking:

-- Why did the damage occur?
-- Is what happened consistent with current understanding?
-- If not, is there an opportunity for a detailed study?
-- Are there any quantitative measurements that can/should be made on the spot?
-- Are there important quantitative measurements that should be made by a follow-up team?

A concerted effort should be made during future earthquakes to obtain quantitative engineering field data such as recording deformations (displacement, slip, strain, etc.) of materials (steel, masonry, reinforced concrete, etc.), structures, and components. These measurements can be used as a basis to determine the inelastic dynamic response and failure mechanisms (i.e., shear failure, flexural failure, fatigue failure, etc.). The same type of questions should be asked in connection with undamaged buildings.

Photographs can be an important tool for documenting potentially perishable quantitative data. However, it is vital to identify and follow-up on opportunities for detailed postearthquake studies. An example is the vibration tests of the remaining uncollapsed bents of the Cypress overpass after the 1989 Loma Prieta earthquake. Equipment that can be deployed quickly into the field will be a key. The state of technology in sensoring, detecting, measuring, non-destructive testings, material property evaluation, etc., has advanced rapidly. Basic technology and hardware components for new state-of-the-art instruments are now available in the open market. It is now feasible to develop a compact, portable field instrument package (including the performance requirements and specifications, design, manufacturing, and packaging through technology integration, and instructions/guidelines) for use in engineering investigations after a damaging earthquake. Portable equipment for subsurface soil investigations will also be essential.

Casualty Estimation

Casualties in future damaging earthquakes are a prime concern to those in public and private sector organizations whose responsibility is life safety. Although considerable attention has been devoted in the past to the general area of earthquake loss estimation (i.e., damage and economic losses), little attention has been devoted to quantitative estimation of earthquake casualties. A critical knowledge gap at present is the integration of predictions of casualty and medical needs with a) loss estimates, b) community vulnerability assessments, and c) rapid damage forecasts.

Technology Transfer

All activities to transfer the technology base (i.e., information, knowledge, and capacity) resulting incrementally from postearthquake investigations will be coordinated by the subcommittee on postearthquake investigations, with each agency having responsibility for funding and implementing its own technology transfer programs and participating in the coordination process of the subcommittee. Mechanisms developed in the NEHRP, will be used to further the process of technology transfer. There are two critical periods: first after the completion of field work, reconnaissance studies, and documentation, and second after the maturation of research. Procedures will be developed to analyze the results of the investigations and distribute appropriate data to the organizations and agencies having earthquake risk-management responsibilities. Included should be organizations and agencies responsible for: basic and applied research in earth sciences, engineering, socioeconomic and policy sciences, land-use planning, building regulations, emergency management, and other hazard-reduction activities.

FUNDING MECHANISMS

In a 1992 report to Congress, FEMA identified the following mechanisms for funding NEHRP postearthquake investigations:

1. Funds from ongoing programs of USGS, NSF, and NIST may be redirected after a damaging earthquake. In the past, these agencies have been able to access up to $5 million of NEHRP funds to conduct field work, perform reconnaissance studies, and support research.

2. FEMA will seek authority to establish a NEHRP postearthquake investigation fund.

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The following references provide information on NEHRP programs, define priorities for postearthquake investigations, and identify gaps in the technology base.

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