U.S. Department of the Interior
U.S. Geological Survey

Earthquake Hazards Program

Five-Year Plan

1998-2002

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EXECUTIVE SUMMARY

Over the next 5 years (1998-2002), the U.S. Geological Survey (USGS) Earthquake Hazards Program (EHP) will continue to contribute scientific and implementation leadership to the National Earthquake Hazards Reduction Program (NEHRP) and the National Earthquake loss reduction Program (NEP) by building on the understanding and databases accumulated over the past 20 years. The USGS EHP will focus on producing usable seismic hazard applications, maintaining comprehensive earthquake monitoring, and carrying out basic earthquake research. These three elements of the program--Products for Earthquake Loss Reduction, Earthquake Information, and Research on Earthquake Occurrence and Effects--are inextricably linked and form a tripod that supports earthquake loss reduction efforts. The effectiveness of each element is dependent on the other two.

Products for Earthquake Loss Reduction

The USGS EHP will produce and demonstrate the application of products that enable the public and private sectors to assess earthquake hazards and implement effective mitigation strategies.

A key contribution of the USGS EHP is the series of national probabilistic seismic shaking hazard maps that are produced and updated periodically with new and refined information. These maps have grown out of the research efforts and systematically quantify the seismic shaking hazard for our Nation. They are used as input for many policy decisions on building codes and land use. In support of these maps, the USGS EHP will produce accessible GIS databases of active earthquake source zones with up-to-date information on slip rates and recurrence intervals.

For selected urban areas at high risk from earthquakes, the USGS EHP plans reports estimating the probabilities of strong earthquakes, detailed maps of shaking amplification and susceptibility to liquefaction and landslides, and planning scenarios of large urban earthquakes. These products will be developed in cooperation with State geological surveys and local committees of users and will be used by planners, engineers, and emergency managers to reduce seismic vulnerability. The USGS will partner with the Federal Emergency Management Agency (FEMA) to evaluate comparative earthquake loss potential for major urban areas across the Nation and to conduct a state-of-the-art estimate of potential earthquake losses for an urban area where earthquake hazard mapping has been completed.

Earthquake Information

The USGS will lead the national program in collecting, interpreting, and disseminating information on earthquakes throughout the United States and significant earthquakes worldwide in support of disaster response, scientific research, national security, earthquake preparedness, and public education.

Because national and international agencies look to the USGS for quick and reliable earthquake information, it is essential to maintain monitoring capabilities nationally and worldwide. Seismic and crustal deformation monitoring networks will provide real-time information for emergency response, as well as record strong-motion data for engineering applications. Products and research of the USGS EHP have been largely data driven (e.g., earthquake probabilities and ground shaking attenuation curves are largely empirically derived), so the EHP invests significant resources in instrumental programs. In addition, USGS has formed partnerships with other public and private entities that use the seismic information to ensure that the important earthquake data are recorded. When large and damaging earthquakes occur within the United States, the USGS will lead post-earthquake studies to ensure archiving of important perishable data and dissemination of lessons learned.

Research on Earthquake Occurrence and Effects

The USGS EHP will pursue earthquake research to understand earthquake occurrence and effects for the purpose of developing and improving hazard assessment methods and loss reduction strategies.

Because the hazard information products of the EHP derive from research efforts, the USGS EHP will continue a major focus on understanding earthquake occurrence in space and time. The physical conditions for earthquake rupture initiation and growth need to be elucidated with field measurements in fault zones and modeling of seismicity, crustal deformation, and other earth science data. Additional critical areas of interest include earthquake triggering, fault interactions, and the role of aseismic slip in relieving the buildup of crustal strain. Understanding in these areas will lead to better estimates of the long-term seismic hazards to the Nation. To address short-term seismic hazard evaluations, studies of earthquake statistics and stress redistribution associated with large earthquakes may facilitate estimates of likelihood and location of future earthquakes.

Reducing future earthquake losses depends on an understanding of the damaging effects of earthquakes. Using data from regional seismic networks, research in this area will address how characteristics of the earthquake source, wave propagation effects, and near-surface geological deposits control the strong shaking. Studies will also investigate the factors that govern susceptibility to ground failure from landsliding, liquefaction, and lateral spreading and the seismic behavior of structures during earthquakes.

INTRODUCTION

Definitions:
Hazard-ground shaking and other natural phenomena that *cannot* be lessened through human intervention.

Risk-the potential for losses to life and the built environment that *can* be controlled or lessened through human intervention

In the past 20 years, the Earthquake Hazards Program (EHP) has been a high profile activity of the U.S. Geological Survey (USGS), and today it continues to be a high priority in the Survey's current thematic emphasis on natural hazards. Authorized by the Earthquake Hazards Reduction Act of 1977 that created the multi-agency National Earthquake Hazards Reduction Program (NEHRP), the EHP has provided much of the problem-focused earth science research and data that has led to a better understanding of the occurrence of earthquakes and their damaging effects.

The purpose of this 5-year plan is to outline the goals and activities of the USGS Earthquake Hazards Program for the period 1998-2002. This plan will be used to guide future activities of the EHP both within and outside the USGS, as well as to explain the scope and intentions of the program to other parties. The plan was developed in late 1996-early 1997 through an intensive process that solicited views from a broad cross-section of the earthquake hazards community drawn from the various seismic regions of the United States.

Over the next 5 years, the USGS EHP will contribute to the reduction of casualties, property damage, and economic losses from earthquakes by providing a firm scientific basis for improved hazard assessments and loss mitigation strategies and by demonstrating the application of new knowledge and techniques to loss reduction activities. The EHP will build upon the understanding and databases produced by the program over the past two decades and pursue the objectives and tasks assigned to the USGS under the NEHRP legislation and the Administration's new National Earthquake loss reduction Program (NEP), defined in the April 1996 report of the National Science and Technology Council, *Strategy for National Earthquake Loss Reduction*. The EHP will focus on providing usable seismic hazard information products while maintaining comprehensive earthquake monitoring and problem-focused earthquake research. This three-pronged effort naturally defines the program in terms of three elements: Products for Earthquake Loss Reduction, Earthquake Information, and Research on Earthquake Occurrence and Effects. These elements are inextricably linked and form a tripod that supports the earthquake loss reduction efforts. The effectiveness of each element is dependent on the other two.

The importance of transferring earthquake hazard information and research findings into the domains of practicing engineers, emergency management personnel, and urban planners was brought home by recent earthquakes in Northridge, California, and Kobe, Japan--57 deaths with $15 billion in direct losses in California and 6,000 deaths with $100 billion in direct losses in Japan. The Northridge event would have been even more catastrophic had building code improvements and retrofit measures not been implemented partly as a result of the long-term research effort in the United States. Our earth science knowledge tells us that seismic events are inevitable and that it is only a matter of time before another U.S. city, probably less well prepared than Northridge, will experience a damaging earthquake. Thus, earthquakes pose one of the great natural threats to the social and economic well-being of our Nation. Because earthquakes cannot be prevented or controlled, mitigation strategies must reduce their consequences. The USGS EHP strategy is to develop and provide a firm understanding of the likelihood and effects of moderate-to-large earthquakes in high risk regions of our country and to transfer this knowledge to people and agencies who can take actions to reduce the impact of the next Northridge-size event on our Nation's cities and people.

As a Federal agency, the USGS must address the earthquake risk reduction needs of the entire country, a challenging responsibility. The decisions and funding commitments entailed in actions to mitigate risk, such as retrofitting a school, are made at State and local levels. Because earthquake damage varies dramatically over short distances due to variations in geology, topography, and other factors, hazard assessments are most accurate and useful when provided at a detailed scale (map scales of 1:24,000 or smaller). The challenge is to fulfill an appropriate Federal role in developing products tailored to a large number of specific localities with disparate needs in the context of limited NEHRP funding. This 5-Year Plan envisions enhanced State and local cooperation as key to increasing not only the resources available for risk reduction efforts, but also the effectiveness of the resulting products.

The USGS has already forged many partnerships with other Federal, State, and local government agencies, as well as with universities and private sector groups, in order to make the most efficient use of national resources. In the framework of a national program, the USGS will provide leadership and seek resources for large-scale instrumental and hazard mapping programs. In an era of declining Federal resources and increasing emphasis on user-oriented information, such partnerships will become increasingly important.

This document identifies priority activities that are the essential components of an effective USGS national earthquake program over the next 5 years. Current funding levels, however, do not permit satisfactory progress in all of these areas. In this document, 5-year priority activities have been assigned to one of three Progress Levels:

❶ Progress Level I: At current funding levels, objectives can be achieved through a concerted effort. Progress I may indicate that the activity does not require a large amount of funding or human resources, that sufficient internal and/or external resources are known to be available, and/or that achieving the objectives is required to meet the needs of the program or its partners.

❷ Progress Level II: Notable progress is expected to be made in these essential activities, but progress will be slower than optimal due to constraints on funding or personnel resources. Activities may be assigned Progress II because they require larger amounts of funding than Progress I activities and/or because outside funding is uncertain.

❸ Progress Level III: Little or no progress is expected in these essential activities because of insufficient funding or human resources. Progress III may indicate that the activity is costly, that no source of outside funding is apparent, and/or that the activity does not have a short-term guarantee of success.

The assignment of activities to these Progress Levels represents a pragmatic strategy for distribution of scarce funding and human resources. The Progress Levels do *not* indicate that any 5-year priority activities would be regarded as expendable in an effective national earthquake program. Temporary or regional departures from this scheme may be necessary, especially for inexpensive efforts that will not impact the overall progress of the plan. Also, innovative projects that advance the overall goals of the plan, but are not listed as priority activities, will be considered, provided the resources to accomplish them can be found without negative impact on the program

THE PROGRAM

I. PRODUCTS FOR EARTHQUAKE LOSS REDUCTION

The USGS EHP will produce and demonstrate the application of products that enable the public and private sectors to assess earthquake hazards and implement effective mitigation strategies.

A key contribution of the USGS earthquake program is the series of national probabilistic seismic shaking hazard maps that are produced and updated periodically with new and refined information. These maps systematically quantify the seismic shaking hazard for the Nation and are used as input for many policy decisions on building codes and land use. For selected urban areas at high risk from earthquakes, the USGS EHP plans specific products that will address the local hazards. Detailed maps of shaking amplification and susceptibility to liquefaction and landslides are planned for high priority cities. In conjunction with these products, the USGS EHP will collaborate and foster ongoing relationships with working groups, professional organizations, and regional consortia to develop the most effective means to communicate seismic hazard issues and ensure the proper transfer of knowledge. In particular, the USGS recognizes the unique role of each of the State geological surveys and State emergency management agencies in communicating earthquake hazards and risk knowledge to their respective governors and populations. The USGS will strive to improve links and coordination of mapping and outreach activities with these agencies.

A. National and Regional

National and regional hazard maps are critical to effective risk mitigation strategies. They are the most often requested products from our program and from other agencies. Building codes based on these maps are a cornerstone for the long-term solution to reducing losses from earthquakes. Earthquake hazard maps will be prominent contributors to the national code changes scheduled for 1997 and 2000. Maps intended for regional and national application are compiled at scales of 1:250,000 or smaller and are relevant to broad scale planning and mitigation strategies for large counties, States, and large regions of the country.

Production of national and regional hazard maps requires integration of information from nearly all aspects of earthquake hazards research as well as the information collected by the seismic and crustal strain monitoring networks. Delineation of seismic source zones and estimates of the location, magnitude, and likelihood of future shocks are developed from records of historical seismicity, geologic investigations of prehistoric earthquakes, and understanding of regional seismotectonics. Seismic wave propagation and attenuation characteristics are derived from regional models of crustal structure and material properties. Near-surface attributes such as geologic setting, soil properties, topography, and groundwater are obtained from comprehensive geologic mapping as well as borehole and other subsurface investigations. Thus, this part of the program delivers many of the intermediate products used to create the hazards maps. Among these products are fault maps, fault slip rates, seismologically and geologically determined earthquake recurrence rates, ground motion attenuation rates, crustal deformation patterns and rates, seismicity maps, and earthquake probability reports.

1. National maps: Products that convey knowledge of earthquake hazards on a national scale.

A key strategy in reducing losses in future earthquakes is the design and construction of structures capable of withstanding levels of seismic shaking expected to occur during the lifetimes of the structures. A mandate of the NEP and among the highest priorities for the USGS EHP is to prepare and update on a periodic basis a series of national probabilistic shaking hazard maps. These maps show the levels of strong ground shaking likely to be experienced over specified exposure times for the purpose of development of building codes. Research conducted or sponsored by the USGS on rates of earthquake recurrence, the nature of seismic sources, and how seismic energy propagates through the Earth's crust are all used in the construction of national and regional probabilistic seismic hazard maps. A set of these maps has been completed for use in planning by industry and the public, and by the Building Seismic Safety Council (BSSC) as part of the 1997 NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings. The building codes that result will determine if new structures will sufficiently withstand strong shaking in future earthquakes.

Over the next 3 years, a set of updated and improved national probabilistic seismic hazard maps will be developed for the 2000 NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings. The goal is to have a set of improved probabilistic hazard maps available in 1999 that continues the broad consensus support appropriate for economically-sensitive regulations, such as building codes.

5-Year Priority Activities:

⇒ Produce in 1999 a set of updated and improved national probabilistic seismic shaking hazard maps for the 2000 NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings. *The USGS will collaborate with the State geological surveys and other organizations in order to accomplish this task.* ❶

⇒ Improve the national probabilistic seismic shaking hazard maps through compilation of a national earthquake catalog with consistent magnitudes, development of improved ground-motion attenuation relations for the Central and Eastern U.S., and increasing knowledge of earthquake source zones and recurrence rates in the United States. ❷

⇒ Improve the national probabilistic seismic shaking hazard maps through collection, analysis, and incorporation of data on crustal deformation in the Central and Eastern U.S. *Analysis of crustal deformation has great potential for improving the seismic shaking hazard maps for the United States east of the Rocky Mountains. Under the current budget restrictions, however, such data are not likely to be collected or analyzed.* ❸

⇒ Collaborate with multidisciplinary working groups and organizations (such as the Applied Technology Council, the Building Seismic Safety Council, the Earthquake Engineering Research Institute, the Insurance Institute for Property Loss Reduction, American Planning Institute, regional consortia, etc.) to develop the most effective means to transfer knowledge of the use, advantages, limitations, and future developments of the national probabilistic seismic shaking hazard maps to various professional groups (engineers, the insurance industry, utility operators, land use planners, etc.). *Collaborative efforts with these groups and cooperative funding of these efforts will leverage the ability of the USGS to provide these crucial knowledge transfer activities.* ❶

⇒ Improve probabilistic and deterministic methods for quantifying seismic hazards, including formally incorporating uncertainty into hazard estimates, especially for areas of relatively low seismicity, such as the East and Intermountain West. ❸

2. Fault maps/databases and earthquake chronologies: Assessment of present and likely future hazards posed by active seismic zones throughout the Nation.

Although the rate of historical earthquake occurrence is the primary input into probabilistic seismic shaking hazard maps, these data are sometimes incomplete or do not reflect the true long-term rate of occurrence of damaging earthquakes. Thus, information on the location of faults and the frequency and size of prehistoric earthquakes are of critical importance in the construction of hazard maps. The locations of faults are commonly determined through geologic mapping. The recently recognized importance of concealed or "blind" faults may necessitate the targeted use of modern geophysical techniques in some areas. The long-term rates of earthquake occurrence on known faults may be inferred from the rates of slip determined geodetically or geologically. They may also be inferred from evidence of prehistoric earthquakes derived from datable material displaced by fault slip or preserved in geologic sections disturbed by earthquake-induced liquefaction or landsliding. During the next 5 years, the EHP will coordinate fault compilations with geologic mapping undertaken by the USGS, State geological surveys, and the academic community, as part of the National Geologic Mapping Act.

5-Year Priority Activities:

⇒ By 1999, compile GIS databases of existing data on active earthquake source zones and make these databases easily accessible to user groups. ❶

⇒ Determine and refine prehistoric earthquake chronologies for high-risk seismically active regions. Continue efforts at current levels in California, Cascadia, New Madrid, and the Wabash Valley. Initiate exploratory efforts in the Northeastern U.S. *Without collaboration and sharing of costs, no other areas will be studied in the foreseeable future.* ❷

⇒ In high-risk seismically active regions, identify active faults and seismic sources and define their geometry by geologic mapping and geophysical imaging. Continue efforts at current levels in California, Cascadia, and the Central U.S. *This work will not be likely to continue at a viable pace without additional funding.* ❸

B. High-Risk Urban Areas:

The strong ground shaking and resulting catastrophic losses in the 1994 Northridge and the 1995 Kobe, Japan, earthquakes reinforced the need for the USGS EHP to concentrate its efforts where the risks are highest, in the Nation's urban areas. Studies in urban areas present the dual challenges of working on local scales and devising new methods for earth science investigations in an urban environment.

Planning officials require seismic hazard maps for metropolitan areas at a scale of 1:24,000 or other appropriate large scales if risks to building sites and structures are to be mitigated. Emergency response officials also use these maps to plan preparedness and recovery efforts. Such maps have the added benefit of drawing the attention of policy makers and the public to the hazards they face. Maps must integrate available earth science information (e.g., near-surface deposits, topography, depth to bedrock, and water table) relevant to risk identification and to mitigation strategy design and implementation. The parameters affecting the spatial distribution of strong shaking and ground failure must be identified, mapped, and catalogued to provide accurate forecasts.

Methods to estimate life loss, trauma, property loss, and indirect economic effects that incorporate information about geology and societal fabric, such as building stock and lifeline characteristics, are critical if the Nation is to effectively mitigate the risks to urban areas. The new earthquake loss estimation software, HAZUS, developed by FEMA offers a new and exciting method for estimating losses that will likely be used by many of the Nation's local and State emergency management agencies. A potential weak link in this package, however, is the geological hazard data that is essential input to the estimates. The USGS must lead the way in devising methods to incorporate earth science models and data into the HAZUS framework and partner with FEMA to refine and demonstrate the application of loss estimations.

1. Urban hazard maps: Products communicating the earthquake hazards facing America's high population centers.

Time and again, emergency response personnel, engineers, land-use planners, and community leaders have expressed the need for large scale (1:24,000) maps that depict hazards and risk in the urban environment. Such hazard and risk maps will involve intensified collection of data and preparation of digital surficial and bedrock geology maps, site response maps, and maps showing the potential hazard from ground failures, including liquefaction and landslides. It is unrealistic that the USGS EHP can accomplish this in all urban areas at risk. The USGS EHP can, however, in cooperation with universities and State geological surveys, produce maps as demonstration projects in certain priority communities to spur work in other urban areas. Criteria for setting priorities among at-risk urban should include the expected earthquake hazard, population and building stock at risk, expected population growth, amount of local cooperation and collaboration, and the amount of work already completed in the area. The USGS EHP can play a particularly important role in cities located in States whose geological surveys lack the personnel or technical expertise to produce urban hazard maps. Many of these cities are in the Eastern and Central U.S.

5-Year Priority Activities:

⇒ By 1999, a partnership of the USGS, FEMA, and State and local governments will complete an initial assessment of comparative earthquake risk for major urban areas across the Nation for the purpose of suggesting Federal priorities for loss reduction activities and increasing awareness of the earthquake threat. The USGS will contribute the geoscience expertise and earthquake information. ❶

⇒ Continue seismotectonic studies in support of urban hazard mapping in California, Cascadia, and the Central U.S. ❷

⇒ In three of the following six urban areas, spanning a range of hazard and risk conditions and tectonic regimes, form local committees of users and experts for the purpose of defining the local needs of government and private industry and identifying partnerships with respect to large-scale seismic hazard maps: the San Francisco Bay region, Los Angeles, Seattle, Memphis, Salt Lake City, Boston. *Little, if any, progress will be made in the three remaining urban areas under current budget projections.* ❶

⇒ For the selected urban areas, develop digital geologic and geotechnical databases and prepare demonstration large-scale seismic hazard maps by 2002. This work will be done in close coordination with State geologists and local committees and, funding permitting, will include:

- compiling digital surficial geology maps;
- preparing ground shaking amplification maps;
- preparing liquefaction and lateral spreading susceptibility maps; and
- preparing landslide susceptibility maps.

The involvement of local committees and State agencies will allow the USGS to seek cooperative funding from the government and private groups that need the map data or to form partnerships with State and local governments to develop hazard maps cooperatively. ❶

⇒ In an urban area with completed large-scale hazard mapping, cooperate with FEMA, emergency management officials, and State geologists to conduct a state-of-the-art loss estimation using HAZUS and incorporating complete digital seismological, geological, and geotechnical data. *Cooperative funding will be sought from FEMA and other government and private groups that will use the loss estimates.* ❶

2. Probability reports: Reports detailing the probabilities of strong earthquakes affecting urban areas.

The USGS EHP must develop methods of making probabilistic forecasts of earthquake occurrence for urban areas in differing tectonic regimes. Apart from California, where geologic histories of many faults have been studied in detail, there is currently considerable uncertainty in our estimates of earthquake recurrence. In the next 5 years, we will select a new area in which to focus these studies.

5-Year Priority Activity:

⇒ By 1999, produce an updated 30-year probability report for the San Francisco Bay Region. ❶

⇒ By 2000, in cooperation with the State geologist and a local committee, create and publish a state-of-knowledge earthquake probability report for Salt Lake City. ❶

3. Earthquake scenarios: Products communicating the range of reasonable earthquake scenarios faced by urban areas.

Urban communities need credible earthquake scenarios in order to form effective mitigation strategies and conduct emergency planning. The USGS and its external partners are uniquely able to provide such information. Using the existing seismological expertise, scientists can estimate the likely levels and distribution of strong shaking from a future large earthquake by synthesizing earthquake source characteristics along with the complicated wave propagation effects. Detailed analyses of geologic and geotechnical databases will provide likely scenarios of liquefaction and seismically induced landslides. Credible planning earthquake scenarios, including vulnerabilities and loss estimates, should be developed in cooperation with other agencies using the GIS technology.

5-Year Priority Activities:

⇒ By 1998, select from the following list, a city in which to create and publish a credible planning earthquake scenario: Seattle, Memphis, Salt Lake City, Boston. ❶

⇒ In coordination with State geologists, State and local emergency management agencies, and local committees, create and publish credible planning earthquake scenarios for the selected city. ❷

C. Outreach:

To ensure the effective and proper use of earthquake hazard products and knowledge developed under the EHP, the USGS will expand its outreach activities. Only through such efforts will the products and knowledge result in appropriate risk mitigation efforts that will reduce losses to life and property in future large earthquakes. The USGS does not have the personnel nor the skills to reach all of the candidate target groups. Thus, a combination of collaborating with professional organizations and government agencies concerned with risk reduction and contracting with those trained in the transfer of technical information will be necessary for effective outreach.

5-Year Priority Activities:

⇒ Collaborate with working groups, professional organizations, and regional consortia to develop the most effective means to communicate seismic hazard issues and to better determine the needs of user groups. *These information transfer activities are ideally funded through cost sharing efforts with the various interested organizations. The USGS can provide the expertise and the working groups, professional organizations, and regional consortia can provide the translation to the needs of their constituencies.* ❶

⇒ Through workshops and publications, provide the public, the private sector, and government agencies with general information on earthquake hazards as well as information specific to their regions. ❶

II. EARTHQUAKE INFORMATION

The USGS will lead the national program in collecting, interpreting, and disseminating information on earthquakes throughout the United States and significant earthquakes worldwide in support of disaster response, scientific research, national security, earthquake preparedness, and public education.

The USGS continues to be the best source of quick and reliable information about felt and damaging earthquakes within the United States and significant earthquakes worldwide. As the global leader in monitoring earthquakes, the USGS coordinates and operates seismic networks at regional, national, and worldwide scales. The USGS also has been a pioneer in using geodetic observations for scientific uses and maintains networks to monitor crustal strain on the West Coast. In addition to these continuous monitoring efforts, when large and damaging earthquakes occur within the United States, the USGS leads post-earthquake scientific studies that ensure archiving of important data and dissemination of lessons learned.

The high cost of installing and maintaining large instrumental networks requires cooperative agreements with other agencies that utilize the seismic information. The USGS will continue its current partnerships and seek new opportunities for collaborative support of the networks that are necessary to effectively provide the program with essential data.

A. Seismic Monitoring

On regional levels, the USGS and cooperating universities operate seismic networks that monitor the activity in areas of high seismicity within the United States. These regional seismic networks, along with the U.S. National Seismograph Network (USNSN), have the capability to provide information about location and size of a local earthquake within half an hour of its occurrence and, in some regions, information about the level of shaking. Regions that have high risk to large urban populations (e.g., Los Angeles, San Francisco) are developing very rapid information systems that distribute information about strong shaking in tens of seconds and, in some instances, may provide warnings before the area experiences the damaging seismic waves.

One area where the USGS program has had a major impact on earthquake mitigation is the collection and analyses of strong-motion data by the National Strong Motion Program (NSMP). Continued collection and rapid dissemination of strong-motion records is essential, since these data contribute directly to EHP products, including seismic hazard evaluations and recommendations for building codes. In concert with the regional networks, the NSMP is striving to collect essential engineering data, including dense arrays in urban areas and representative regional coverage across the country.

Through its National Earthquake Information Service (NEIS), the USGS has long been recognized as the primary source of information for significant earthquakes around the world. To collect the worldwide data, the USGS cooperates with several organizations to operate a global network of seismograph stations. Using data from this network and other foreign seismic stations, the USGS reports within tens of minutes on the occurrence of significant earthquakes worldwide, as well as maintaining comprehensive national and world earthquake catalogs. This rapid earthquake information is important for tsunami warnings, as well as preparing emergency responses.

Since advances in the research and subsequent applied products of the EHP have been largely data driven, the archives of seismic data collected by the various networks and arrays are very important. These databases provide a basis for understanding the geologic processes that cause earthquakes, defining buried active faults, assessing earthquake potential, defining hazards, and documenting seismic behavior of manmade structures. Especially important are the strong-motion recordings from larger earthquakes that have direct impact on engineering design and building codes.

5-Year Priority Activities:

⇒ By 2000, integrate the USNSN and EHP-supported regional seismic networks into the National Seismic System (NSS) with the goal of monitoring U.S. earthquakes down to magnitude 3. Regional seismic monitoring will be maintained in cooperation with universities in high seismicity, populated areas of California, the Pacific Northwest, the Central Mississippi Valley region, Nevada, Utah, Alaska, and the Eastern U.S. These networks will provide complete and easily accessible digital databases of earthquake parameter and waveform data. Quick seismic information will also be provided to Federal and State agencies, private industries, media, and the public. *With USGS support, networks will be responsible for seeking cooperative funding from Federal and State agencies as well as private industry.* ❶

⇒ Through the NSMP, maintain instruments in seismically active regions to quantify free-field strong ground shaking. These strong-motion networks will be operated in conjunction with the regional seismic networks. There will be a timely and easily accessible database of all significant strong-motion records for the engineering community. *Funding for the dense urban networks will be sought through cooperatives with local agencies.* ❶

⇒ In cooperation with the Incorporated Research Institutions for Seismology (IRIS), operate the Global Seismographic Network (GSN) to maintain the capability of NEIS to provide accurate and timely information on the occurrence of significant earthquakes worldwide. Also, maintain complete national and world earthquake catalogs. *The GSN supports global seismic research and contributes data for verification of the Comprehensive Test Ban Treaty. The USGS FY 1998 budget requests $3.0 million of additional funding to maintain its part of the cooperative GSN.* ❶

⇒ Develop improved techniques for rapidly determining earthquake source parameters (e.g., location, size, type of faulting, direction of fault rupture) from regional and global network data for better estimates of earthquake damage patterns and impacts. ❷

⇒ Upgrade outdated analog regional networks and strong-motion sites to digital recording with modern telemetry capabilities so essential seismic data can be collected more effectively and efficiently. *Funding for the hardware improvements of existing networks is being sought through a budget initiative process in the Department of the Interior and through other cooperative efforts.* ❸

⇒ In regions of high risk, develop prototype rapid information systems for innovative emergency response efforts. *Progress will depend on funding for these new systems from cooperating government agencies and the private sector, as has been realized in southern California through the TriNet initiative orchestrated by the USGS, the California Institute of Technology, and the California Division of Mines and Geology.* ❶

B. Crustal Strain Monitoring

Crustal deformation across seismically active regions is monitored by the USGS and cooperating universities and local agencies with leveling and laser-ranging surveys, Global Positioning System (GPS) measurements, and continuous instrumental measurements of fault displacement and crustal strain. These measurements of the regional deformation field and strain accumulation near faults are important for future probabilistic hazard estimates, as well as for improving the understanding of the earthquake process. In regions where it is difficult to comprehensively map active faulting, such as the eastern U.S., geodetic strain rates give one of the few quantitative measures of potential seismic hazard. Recent advances in technology and large decreases in the cost of instrumentation have enabled continuous (1-100 measurements per day) determinations of positions at fixed GPS sites, providing a practical way to continuously track crustal deformation.

One promising new field that the USGS will pursue is Interferometric Synthetic Aperture Radar, a satellite technology for mapping small changes in ground deformation. Large areal maps of the ground deformation will give clear images of deformation accompanying and following large earthquakes. The technology may also elucidate regional strain accumulation around faults between earthquakes.

5-Year Priority Activities:

⇒ Maintain crustal deformation monitoring in active seismic areas of California, the Pacific Northwest, the Central U.S., Nevada, Utah, and Alaska for understanding the strain fields associated with earthquakes. ❶

⇒ Establish geodetic measurements in the regions of the Eastern U.S., where little is known about the deformation rates, in order to provide first-order information on the strain rates that determine the regional seismic hazards. ❸

⇒ Cooperate with the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF) in testing dense continuous GPS monitoring capability in southern California for scientific observation of crustal deformation and real-time monitoring of geologic and manmade structures. *Progress depends on cooperative funding for the Southern California Integrated GPS Network (SCIGN), which is being provided by USGS, NASA, NSF, and private donations.* ❶

⇒ Investigate Interferometric Synthetic Aperture Radar techniques for providing map images of fault slip and areal crustal deformation associated with earthquakes. ❷

⇒ Develop a comprehensive national database of continuous geodetic measurements made by various agencies for use in scientific investigations. *Work is to be carried out cooperatively with other large geodetic organizations (UNAVCO, National Oceanic and Atmospheric Administration (NOAA), National Geodetic Survey).* ❸

C. Post-earthquake Investigations

Large and destructive earthquakes provide opportunities to quickly collect great amounts of damage and earth science data. Substantial advances in understanding of earth science and engineering issues have followed important domestic and foreign events, such as the 1994 Northridge, California, and 1995 Kobe, Japan, earthquakes. The USGS will appropriately respond to damaging domestic earthquakes with portable seismic instrumentation, geodetic measurements, geologic field investigations, and damage evaluations. Furthermore, the USGS will cooperate with U.S. and foreign institutions in investigations of foreign earthquakes.

5-Year Priority Activities:

⇒ Work with government agencies and universities to coordinate scientific earthquake responses and post-earthquake investigations. Focus on providing immediate hazard information and investigating the faulting process and the earthquake source, seismic shaking and ground failure effects, and damage patterns. ❶

⇒ Provide, within 2 years of a significant earthquake, a report of the post-earthquake investigations for the public. Prepare an in-depth report of scientific findings within 4 years. ❶

III. RESEARCH ON EARTHQUAKE OCCURRENCE AND EFFECTS

The USGS EHP will pursue earthquake research to understand earthquake occurrence and effects for the purpose of developing and improving hazard assessment methods and loss reduction strategies.

The Research element is closely linked to the Products and Information elements. Research has provided the basis for the current state of knowledge in NEHRP/NEP and is implicit in the development of current and future products for earthquake loss reduction. The earthquake data collected by USGS-supported seismic and crustal deformation networks are essential to, and often drives, research progress. Some of the specific research ventures listed under this element have primarily long-term goals, but broad geographic application and potentially great impact. High-risk urban areas are ideal field sites for many research efforts, but efficient progress in some research areas requires data acquired in other parts of the United States and the world or in specially designed laboratory and field experiments.

The USGS and NSF are the two NEHRP/NEP agencies with primary responsibility for supporting research to characterize the complex natural systems that generate earthquakes. In contrast with NSF, the USGS supports research for which an expectation of risk reduction, in the short or long term, can be demonstrated, as well as research requiring long continuity of data collection. USGS EHP research activities culminate in application of scientific advances to experimental or prototypical methods for loss reduction.

A. Physics of Earthquake Occurrence

Seismic hazard assessments rely upon estimates of the locations, sizes, and probabilities of future earthquakes. Current generation products presume that earthquakes recur where they have occurred in the historic or geologic past at rates similar to their past rates of occurrence. Even if this assumption about occurrence rates is correct, it does not always yield useful hazard assessments because past earthquake histories have not been reconstructed for many quake-prone areas. Also, where data do exist, for example on the southern San Andreas fault in California, time periods between successive earthquakes vary by factors of two to three. Reducing uncertainty in characterizing earthquake sources requires identifying the physical variables that govern where earthquakes can happen, how large they will be, and how often they will occur.

1. Understanding earthquake rupture:

The initiation and arrest of seismic rupture govern the location and ultimate size of an earthquake. While it is generally agreed that increasing tectonic stress and/or fluid pressure initiates earthquakes, further quantification of this concept has proven elusive. Fault zone geologic or geometric heterogeneity, frictional properties, mechanical and chemical effects of pore fluids, and stress concentrations potentially control rupture initiation and arrest, but the relative roles of these and other factors are unclear in the absence of data from the depths where earthquakes initiate.

5-Year Priority Activities:

⇒ Conduct research on the initiation, propagation, and arrest of seismic rupture and test the resulting hypotheses by geologic, geodetic, seismological, and other relevant field observations, laboratory experiments, and numerical simulation. ❷

⇒ Acquire data on stress, temperature, pore pressure, rock/fluid compositions, and physical properties at seismogenic depths in active fault zones, as well as laboratory measurements of physical properties under in situ conditions. *Progress is contingent upon external funding. In particular, the goal of drilling a 3.5-km deep pilot scientific borehole at Parkfield, California, is contingent upon the success of collaborative efforts by USGS, NSF, Department of Energy, and international partners to obtain funding for this effort.* ❸

⇒ Continue the focused fault-monitoring experiment at Parkfield, California. An independent review in 1993 concluded that Parkfield remains the best place to "trap" a moderate-sized earthquake and thereby answer important scientific questions about the earthquake source. ❷ *One-time funding for infrastructure improvements is a higher Progress Level.*

2. Understanding earthquake recurrence.

Even where extensive information about past earthquakes, fault structures, and current deformation rates exists, accurately estimating future earthquake probabilities from this information has many uncertainties. Earthquake scientists still debate what a lack of background seismicity or a high geodetically measured strain rate indicates about the earthquake potential of a fault. Increased understanding in these areas will reduce the uncertainty in hazard estimates, especially where limited information about past earthquake history is available.

5-Year Priority Activities:

⇒ Investigate the factors controlling earthquake recurrence. ❶

⇒ Collect and analyze geologic evidence of prehistoric earthquakes and other data to determine the time periods between successive earthquakes in different tectonic settings. ❷

⇒ Use geodetic and geologic techniques to determine crustal strain rates, compare these strain rates with long-term seismic moment release, fault slip rates, and modeled plate rates, and investigate how all of these quantities are related to future earthquake potential. ❷

3. Foreshocks, aftershocks, stress transfer, and remote triggering.

In the aftermath of a significant earthquake, citizens and public safety officials are always concerned about the implications for future earthquakes in the area. Recent work on earthquake statistics enabled forecasts of aftershock probabilities to be issued following the Northridge earthquake, and aftershock probabilities have been identified by FEMA as one of the critical pieces of seismological information for facilitating emergency response and recovery. A class of immediate foreshocks has been identified and analyzed; based on this knowledge, the probability of an earthquake being followed by a larger "main" shock has been calculated for southern California (where potential public warnings have been based on these calculations) and Nevada.

5-Year Priority Activities :

⇒ Develop and test hypotheses to explain the features of aftershocks and foreshocks that have been identified through statistical analysis. Determine if foreshocks further from and longer before mainshocks can be recognized, such as those preceding the 1989 Loma Prieta and 1992 Landers, California, earthquakes. ❶

⇒ Continue study of the stress changes produced by significant earthquakes, which may allow the most likely locations of aftershocks to be forecast, as well as further mainshocks within a period of time. Express results as earthquake probability estimates. ❶

⇒ Attempt to understand and quantify the potential for major earthquakes to trigger seismicity at great distance from the mainshock, as happened with the 1992 Landers earthquake. ❸

4. Intermediate-term forecasting and short-term prediction.

Improvements in earthquake probability estimates are steps toward the challenging goal of issuing intermediate-term and short-term warnings before damaging earthquakes. Intermediate-term (months to a few years) warnings could stimulate accelerated mitigation measures, while short-term (hours to days) predictions could permit emergency management agencies to open disaster-response field offices before an earthquake, a procedure that speeds recovery from other types of natural disasters. Collaborative research with social scientists is required to determine the optimal uses of earthquake forecasts and predictions. Some capability for intermediate-term forecasting may emerge as earthquake recurrence and stress transfer are more fully understood. For short-term prediction, a critical issue is whether any observable signals, besides foreshocks, are generated before an impending earthquake. Signals preceding the Loma Prieta (electromagnetic and strain) and Kobe (hydrologic and geochemical) earthquakes are possible examples. The decade-long baselines of data already acquired at Parkfield, California, are irreplaceable for identifying intermediate-term changes in strain rates and other variables and assessing their significance.

5-Year Priority Activities :

⇒ Continue the experiment at Parkfield to monitor possible earthquake precursors under controlled conditions such that their relationship to the earthquake generation process can be established. ❷ *One-time funding for infrastructure improvements is a higher Progress Level.*

⇒ Investigate reports and observations of possible intermediate- and short-term earthquake precursors associated with major earthquakes. ❸

⇒ Authoritatively evaluate credible methods for earthquake prediction proposed by researchers worldwide through the National Earthquake Prediction Evaluation Council (NEPEC). ❷

The NEPEC evaluates scientifically based earthquake forecasts and probability estimates to advise the Director of the USGS in decisions relating to the issuance of Geologic Hazard Warnings or the approval of publications with public impact. NEPEC is chaired by a non-USGS earthquake scientist; other members represent the USGS as well as other organizations. NEPEC is funded by the USGS EHP.

B. Earthquake Effects

Among the most important contributions of the EHP to reducing earthquake losses in the United States are improving the understanding and modeling of damaging earthquake effects. These effects include strong ground shaking, failure and deformation of unstable ground, and the impact of these geologic effects on manmade structures. Improving current techniques for forecasting these effects is critical to cost-effective earthquake risk reduction.

1. Earthquake source effects on strong ground shaking and tsunamis.

Empirical relations based on strong-motion recordings from past earthquakes are used by engineers in designing structures, but this approach underpredicted some of the highest accelerations at sites close to the Northridge earthquake epicenter. Synthetic ground motion histories can overcome such limitations by providing engineers with a range of expected ground motions, including those enhanced by highly directional rupture propagation, hanging wall effects, or pulse duration.

5-Year Priority Activities:

⇒ Develop improved methods to calculate synthetic seismograms for future earthquakes, incorporating improved understanding of the rupture process and information about the fault and the properties of the surrounding Earth's crust. These synthetic seismograms must accurately simulate a number of parameters used by structural and geotechnical engineers: peak acceleration, ground velocity and displacement; response spectra; and shaking duration. *Cooperative efforts may be possible, such as with Caltrans which is currently funding development of synthetic ground-motion time histories for some California bridges.* ❶

⇒ Determine from global seismic data which characteristics of the earthquake source govern tsunami-generating potential and develop methods for rapidly estimating these characteristics from seismograms so they can be implemented in tsunami warning procedures. *The USGS is collaborating with NOAA to upgrade regional seismic networks in the Pacific Northwest including Alaska to provide rapid on-scale seismic data for the tsunami warning service that NOAA operates.* ❸

2. Wave propagation effects on strong ground shaking.

Propagation of seismic waves to the region surrounding the seismic source adds another level of complexity in predicting strong ground shaking. Reflections from and focusing by subsurface geologic structures can amplify damaging seismic radiation. Wave propagation effects in sedimentary basins probably caused damage in west Los Angeles and Santa Monica (including the collapse of highway I-10) during the 1994 Northridge earthquake. These effects will profoundly influence the patterns of strong shaking to be experienced from local earthquakes in and adjacent to many at-risk cities, including Los Angeles, San Jose, Seattle, and Portland.

5-Year Priority Activity:

⇒ In Fall 1997, hold a workshop to select an earthquake-prone city (for which strong motion recordings or other site-response data exist) in which to test 3-D numerical simulations of basin response to strong shaking. ❶

⇒ By 2000, characterize basin structure for the selected city well enough to test 3-D numerical simulations of basin response. Conduct shallow, high-resolution, active-source seismic surveys to determine compressional and shear wave velocities in the upper 5 km. *An emphasis will be placed on funding the work cooperatively with other organizations.* ❷

3. Site-specific shaking hazard.

Earthquakes typically produce complex damage patterns with pockets of enhanced destruction the size of a city block or as large as a few square kilometers. Ground motion records from aftershocks of the Northridge earthquake showed site response on alluvium enhanced by a factor of up to 10 over nearby hard-rock sites in heavily damaged areas such as Sherman Oaks. Topography and near-surface geology contribute to this variability, but unidentified factors remain. Identification of these factors and their quantitative prediction are required if the factors are to be incorporated in urban hazard maps so that they can be taken into account in land-use planning and engineering decisions.

5-Year Priority Activities:

⇒ Seek the reason for enhanced shaking response by collecting data on subsurface seismic velocities and densities at sites where there are weak and strong-motion recordings of enhanced ground motion. ❷

⇒ Evaluate the importance of nonlinear soil response for sites representative of conditions in high-risk urban areas. ❸

4. Ground failure.

Landsliding, liquefaction, and lateral spreading are major contributors to earthquake destruction. During the Northridge earthquake, significant ground failure took place at sites previously evaluated as safe from these hazards, emphasizing the need for better understanding of ground failure mechanisms.

5-Year Priority Activities:

⇒ Record acceleration, pore pressure and other transient parameters accompanying ground failure in significant earthquakes and characterize ambient physical properties of the soils in which failures occur. Use the data to improve theoretical understanding of liquefaction susceptibility and landslide triggering, including the effect of shaking duration. *Progress will depend on funding from outside sources.* ❸

⇒ Develop techniques to estimate the permanent ground deformation and displacement resulting from earthquake-induced landslides and liquefaction. ❸

5. Response of structures.

Seismic ground motion and ground failure lead to earthquake losses and casualties primarily through their effects on buildings and lifelines. Collaboration with structural and geotechnical engineers to study soil-structure interaction and the relationship of ground shaking and deformation with structural damage can improve engineering techniques for earthquake-resistant design and seismic retrofitting.

5-Year Priority Activities:

⇒ Analyze existing data to examine the response of structures, to identify the parameters of ground motion that control damage to structures (such as acceleration, velocity, shaking duration, and spectral content), and to investigate soil-structure interaction. ❶

⇒ Record data documenting input ground motion as well as structural response in selected structures in seismically active areas. *Partnerships with professional associations, Federal and State agencies, and building owners must be sought for instrumentation of structures.* ❷

Five Year Plan Priority Tasks by Progress Level

PROGRESS LEVEL ❶	
I.A.1	Produce in 1999 a set of updated and improved national seismic shaking hazard maps.
I.A.1	Collaborate with professional organizations to develop effective means to transfer knowledge on national probabilistic seismic shaking hazard maps.
I.A.2	By 1999, compile GIS databases of existing data on active earthquake source zones.
I.B.1	By 1999, complete an initial assessment of comparative earthquake risk for major urban areas.
I.B.1	For three urban areas form local committees to define the needs of government and private industry and identifying partnerships with respect to large-scale seismic hazard maps
I.B.1	For these selected urban areas, develop digital geologic and geotechnical databases and prepare demonstration large-scale seismic hazard maps by 2002.
I.B.1	In one urban area, cooperate with FEMA, emergency management officials, and State Geologists to produce a state-of-the-art loss estimation model.
I.B.2	By 1999, produce an updated 30-year probability report for the San Francisco Bay Region.
I.B.2	By 2000, create and publish a state-of-knowledge earthquake probability report for Salt Lake City.
I.B.3	By 1998, select a city in which to create and publish a credible planning earthquake scenario.
I.C	Develop effective means to communicate seismic hazard issues and to better determine the needs of user groups.
I.C	Provide the public, the private sector, and government agencies with general information on earthquake hazards as well as information specific to their region.

PROGRESS LEVEL ❶ (CONTINUED)	
II.A	By 2000, establish a single National Seismic System (NSS) for monitoring U.S. earthquakes down to magnitude 3.
II.A	Maintain National Strong Motion Program instruments in seismically active regions.
II.A	Operate a global earthquake monitoring network.
II.A	In regions of high risk, develop prototype rapid information systems.
II.B	Maintain crustal strain monitoring in active seismic areas.
II.B	Cooperate with NASA and NSF in testing dense continuous GPS monitoring capability in southern California.
II.C	Coordinate scientific post-earthquake responses and conduct investigations.
II.C	Provide timely reports of significant post-earthquake investigations.
III.A.1	Investigate the factors controlling earthquake recurrence.
III.A.3	Develop and test hypotheses to explain features of aftershocks and foreshock.
III.A.3	Investigate stress changes produced by significant earthquakes to probabilistically forecast ensuing seismicity.
III.B.1	Develop improved methods to calculate synthetic seismograms for future earthquakes
III.B.2	In Fall 1997, select a city in which to test 3-D numerical simulations of basin response to strong shaking.
III.B.5	Analyze existing data to identify the parameters of ground motion that control damage to structures.

PROGRESS LEVEL ❷	
I.A.1	Compile national earthquake catalog, improve attenuation relations in the Central and Eastern US, and improve knowledge of source zones and recurrence rates in the Central and Eastern US.
I.A.2	Determine and refine prehistoric earthquake chronologies for high risk seismically active regions.
I.B.1	Continue seismotectonic studies to support urban hazard mapping in California, Cascadia, and the Central U.S.
I.B.3	Publish credible planning earthquake scenarios for one selected city.
II.A	Develop improved techniques for rapidly determining earthquake source parameters.
II.B	Investigate Interferometric Synthetic Aperture Radar mapping of earthquake-related crustal deformation.
III.A.1	Conduct research on initiation, propagation, and arrest of seismic rupture and test resulting hypotheses.
III.A.1	Continue the focused fault-monitoring experiment at Parkfield, California.
III.A.2	Collect and analyze geologic and other data to determine the time periods between successive earthquakes.
III.A.2	Compare geodetic and geologic strain rates to rates of seismic moment, fault slip and plate motion; relate all to earthquake potential.
III.A.4	Continue the experiment at Parkfield to monitor possible earthquake precursors.
III.A.4	Authoritatively evaluate credible methods for earthquake prediction.
III.B.2	By 2000, characterize basin structure beneath a selected city and test 3-D numerical simulations of basin response to strong shaking.
III.B.3	Seek the reason for enhanced shaking at local sites.
III.B.5	Record data documenting input ground motion as well as structural response in selected structures

PROGRESS LEVEL ❸	
I.A.1	Collect and analyze data on crustal deformation in the Central and Eastern US.
I.A.1	Develop new methods for quantifying seismic hazards in areas where damaging earthquakes are infrequent.
I.A.2	In high risk seismically active regions, identify active faults and seismic sources and define their geometry.
II.A	Upgrade outdated analog regional networks and strong-motion sites.
II.B	Initiate geodetic measurements in the Eastern US.
II.B	Develop a national database comprising continuous geodetic measurements.
III.A.1	Acquire data on material properties and physical conditions at seismogenic depths in active fault zones and conduct laboratory measurements of physical properties under in situ conditions.
III.A.3	Investigate the potential for major earthquakes to trigger seismicity at great distance from the mainshock.
III.A.4	Evaluate reports and observations of possible intermediate- and short-term earthquake precursors.
III.B.1	Determine which characteristics of the earthquake source govern tsunami-generating potential.
III.B.3	Evaluate role of nonlinear soil response for sites representative of conditions in high-risk urban areas.
III.B.4	Measure physical conditions associated with quake-induced ground failures to understand failure processes.
III.B.4	Develop techniques to predict deformation and displacement from quake-induced ground failures.

THE PLANNING PROCESS

This plan was developed through an intensive seven-month process that involved a broad cross-section of stakeholders in the USGS EHP. Led by the authors of this report, the planning process formally began in October 1996 with the drafting of a skeletal program plan. This skeletal plan served as an initial framework for discussing the future direction and priorities of the EHP.

Views and comments on the draft skeletal plan and recommendations on future program direction were solicited from a wide audience of program stakeholders. Over 400 copies of the draft plan were mailed for comment to State geologists and emergency managers, to representatives of Federal agencies, to leaders in the broad earthquake hazards community, and to individuals who had submitted grant proposals to the EHP in the previous 3 years. More than 80 responses were received. Five invitational workshops, heavily involving external program participants and customers, sought views and recommendations regarding specific program components or program efforts in particular seismic regions. The topics and participants of these workshops are listed at the end of this section. Likewise, views and recommendations of USGS program personnel were solicited through two internal workshops.

Findings and recommendations from the mailing and workshops were summarized and discussed in late January 1997 in a concluding wrap-around workshop involving external stakeholders, most of whom had participated in one of the initial workshops, and USGS EHP leadership. Final recommendations on the draft plan were developed. Following this workshop, the authors revised the draft plan. In mid-February, the USGS Earthquake Hazards Program Council reviewed the revised plan and decided what rates of progress could be expected on the many program priority activities in the context of available program resources. With this additional input, the program plan was finalized. In April 1997 the plan was submitted to the USGS Associate Chief Geologist for Science.

The planning process benefited greatly from the interest, thought and participation of numerous individuals spanning the breadth of the earthquake hazards community--earth sciences, engineering, urban planning, insurance and business--and the several seismic regions of the U.S. The authors thank these many people for their involvement and contributions. Finally, this intensive effort could not have succeeded without the support and dedication of Joyce A. Costello and Linda R. Huey of the USGS Earthquake Hazards Program Office.

Seismic Networks Workshop

Denver, Colorado — November 8, 1996

Harley Benz, convener	U.S. Geological Survey
Walter Arabasz	University of Utah
Michael Blackford	National Oceanic & Atmospheric Administration
Michael Blanpied	U.S. Geological Survey
Roger Borcherdt	U.S. Geological Survey
Ray Buland	U.S. Geological Survey
James Goltz	EQE International, Inc.
Gary Hart	Hart Consultant Group
Egill Hauksson	California Institute of Technology
Robert Herrmann	Saint Louis University
Klaus Jacob	Columbia University
Douglas Johnson	Columbia University
Stephen Malone	University of Washington
Jim Mori	U.S. Geological Survey
Mary Fran Myers	University of Colorado
David Oppenheimer	U.S. Geological Survey
Robert Page	U.S. Geological Survey
William Prescott	U.S. Geological Survey
Evelyn Roeloffs	U.S. Geological Survey
Barbara Romanowicz	University of California, Berkeley
John Schneider	Union Pacific Railroad
David Simpson	Incorporated Research Institutions for Seismology
Ivan Wong	Woodward-Clyde Federal Services
Max Wyss	University of Alaska

Intraplate Seismic Regions Workshop

St. Louis, Missouri — November 14-15, 1996

Anthony Crone, co-convener	U.S. Geological Survey
Eugene Schweig, co-convener	U.S. Geological Survey
Lee Allison	Utah Geological Survey
Robert Bauer	Illinois State Geological Survey
Robert Bucknam	U.S. Geological Survey
Frederick Chester	Saint Louis University
Tammie Dreher	South Carolina Emergency Preparedness Division
John Ebel	Boston College
R. T. Elliott	State Farm Fire and Casualty Company
Edward Fratto	New England States Emergency Consortium
Joan Gomberg	U.S. Geological Survey
Sherman Greer	Evansville-Vanderburgh Co. (IN) Emergency Management
Robert Herrmann	Saint Louis University
Warner Howe	Private consultant
Arch Johnston	University of Memphis
Jill Johnston	University of Memphis

Keith Kelson	William Lettis & Associates, Inc.
John Kiefer	Kentucky Geological Survey
Larry Fellows	Arizona Geological Survey
Michael Machette	U.S. Geological Survey
James McCalpin	Geo-Haz Consulting, Inc.
Jim Mori	U.S. Geological Survey
Stuart Nishenko	Federal Emergency Management Agency
Robert Page	U.S. Geological Survey
Evelyn Roeloffs	U.S. Geological Survey
Christopher Sanders	Southeast Missouri State University
John Sims	U.S. Geological Survey
Gabriel Toro	Risk Engineering, Inc.
Terry Tullis	Brown University
Randall Updike	U.S. Geological Survey
Russell Wheeler	U.S. Geological Survey
James Wilkinson	Central United States Earthquake Consortium
Mary Lou Zoback	U.S. Geological Survey

California Workshop

Los Angeles, California — November 22, 1996

Jim Mori, co-convener	U.S. Geological Survey
David Schwartz, co-convener	U.S. Geological Survey
Ralph Archuleta	University of California, Santa Barbara
Gregory Beroza	Stanford University
John Boatwright	U.S. Geological Survey
Edward Bortugno	California Office of Emergency Services
James Davis	California Division of Mines & Geology
Douglas Dreger	University of California, Berkeley
William Foxall	Lawrence Livermore Laboratory
Gary Fuis	U.S. Geological Survey
Stephen Hartzell	U.S. Geological Survey
Thomas Holzer	U.S. Geological Survey
David Jackson	University of California, Los Angeles
Jeffrey Johnson	California Seismic Safety Commission
Lucile Jones	U.S. Geological Survey
Arthur McGarr	U.S. Geological Survey
Andrew Michael	U.S. Geological Survey
Daniel Ponti	U.S. Geological Survey
William Prescott	U.S. Geological Survey
Evelyn Roeloffs	U.S. Geological Survey
Richard Roth	California Department of Insurance
William Savage	Pacific Gas & Electric Company
Paul Silver	Carnegie Institute of Washington
John Sims	U.S. Geological Survey
Paul Somerville	Woodward-Clyde Federal Services
Susan Tubbesing	Earthquake Engineering Research Institute

Earthquake Risk and Engineering Workshop

Burlingame, California — January 16-17, 1997

Roger Borcherdt, co-convener	U.S. Geological Survey
Arthur Frankel, co-convener	U.S. Geological Survey
Norman Abrahamson	Private consultant
John Boatwright	U.S. Geological Survey
Bruce Bolt	University of California, Berkeley
Mehmet Celebi	U.S. Geological Survey
Allin Cornell	Stanford University
C.B. Crouse	Dames & Moore
James Davis	California Division of Mines & Geology
James Dieterich	U.S. Geological Survey
Kathleen Haller	U.S. Geological Survey
William Holmes	Rutherford & Chekene
R. Joe Hunt	Lockheed Martin Energy Systems
Do Kim	Insurance Institute for Property Loss Reduction
E.V. Leyendecker	U.S. Geological Survey
Arthur McGarr	U.S. Geological Survey
Walter Mooney	U.S. Geological Survey
Jim Mori	U.S. Geological Survey
Stuart Nishenko	Federal Emergency Management Agency
Guy Nordenson	Ove Arup & Partners
Daniel O'Connell	U.S. Bureau of Reclamation
Robert Page	U.S. Geological Survey
William Petak	University of Southern California
Mark Peterson	California Division of Mines & Geology
Maurice Power	Geomatrix Consultants, Inc.
Evelyn Roeloffs	U.S. Geological Survey
Christopher Rojahn	Applied Technology Council
Charles Scawthorn	EQE International, Inc.
David Schwartz	U.S. Geological Survey
Haresh Shah	Stanford University
Robert Smith	University of Utah
Paul Somerville	Woodward-Clyde Federal Services
J. Carl Stepp	Earthquake Hazards Solutions
Randall Updike	U.S. Geological Survey

Pacific Northwest Workshop

Seattle, Washington — January 23, 1997

Craig Weaver, convener	U.S. Geological Survey
John Aho	CH2M Hill
Donald Ballantyne	EQE International, Inc.
Jack Bernhardsen	Tacoma Public Utilities
Derek Booth	University of Washington

Gary Carver	Humbolt State University
Rodney Combellick	Alaska Division of Geological & Geophysical Surveys
David Cassel	Oregon Emergency Management
James Dieterich	U.S. Geological Survey
Christopher Goldfinger	Oregon State University
Paul Grant	Shannon & Wilson, Inc.
Roger Hansen	University of Alaska
Roy Hyndman	Geological Survey of Canada
Christine Jonientz-Trisler	Federal Emergency Management Agency
Steven Kramer	University of Washington
John Lahr	U.S. Geological Survey
Jim Mori	U.S. Geological Survey
Alan Nelson	U.S. Geological Survey
Robert Page	U.S. Geological Survey
David Perkins	U.S. Geological Survey
Evelyn Roeloffs	U.S. Geological Survey
Garry Rogers	Geological Survey of Canada
Eugene Schweig	U.S. Geological Survey
John Sims	U.S. Geological Survey
Stewart Smith	University of Washington
William Steele	University of Washington
Gerry Uba	Metro-Planning Department, Portland
Randall Updike	U.S. Geological Survey
Timothy Walsh	Washington Department of Natural Resources
Ray Wells	U.S. Geological Survey
Colin Williams	U.S. Geological Survey
Ivan Wong	Woodward-Clyde Federal Services

Wrap-Around Workshop

San Diego, California — January 30-31, 1997

Evelyn Roeloffs, convener	U.S. Geological Survey
Norman Abrahamson	Private consultant
Michael Blanpied	U.S. Geological Survey
John Boatwright	U.S. Geological Survey
Roger Borcherdt	U.S. Geological Survey
Robert Bucknam	U.S. Geological Survey
Gary Carver	Humboldt State University
Frederick Chester	Saint Louis University
George Choy	U.S. Geological Survey
Gary Christenson	Utah Geological Survey
James Davis	California Division of Mines & Geology
James Dieterich	U.S. Geological Survey
Arthur Frankel	U.S. Geological Survey
Edward Fratto	New England States Emergency Consortium
Thomas Holzer	U.S. Geological Survey

David Jackson	University of California, Los Angeles
Klaus Jacob	Columbia University
Samuel Johnson	U.S. Geological Survey
Arch Johnston	University of Memphis
Thomas Jordan	Massachusetts Institute of Technology
Jeffrey Kimball	Department of Energy
P. Patrick Leahy	U.S. Geological Survey
Arthur McGarr	U.S. Geological Survey
Charles Meade	National Academy of Sciences
Walter Mooney	U.S. Geological Survey
Jim Mori	U.S. Geological Survey
Daniel O'Connell	U.S. Bureau of Reclamation
Robert Page	U.S. Geological Survey
Chris Poland	Degenkolb Engineers
Erdal Safak	U.S. Geological Survey
David Schwartz	U.S. Geological Survey
Eugene Schweig	U.S. Geological Survey
Paul Silver	Carnegie Institute of Washington
David Simpson	Incorporated Research Institutions for Seismology
John Sims	U.S. Geological Survey
Stuart Sipkin	U.S. Geological Survey
Debby Steffen	California Office of Emergency Services
J. Carl Stepp	Earthquake Hazards Solutions
Terry Tullis	Brown University
Randall Updike	U.S. Geological Survey
Robert Volland	Federal Emergency Management Agency
Timothy Walsh	Washington Department of Natural Resources
Craig Weaver	U.S. Geological Survey
James Wilkinson	Central United States Earthquake Consortium
Colin Williams	U.S. Geological Survey
Mary Lou Zoback	U.S. Geological Survey