Seismographic Networks:

Problems and Outlook for the 1980s

Report of the Workshop on Seismographic Networks
Committee on Seismology
Commission on Physical Sciences, Mathematics, and Resources
National Research Council

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THOMAS V. McEVILLY, Chairman
Department of Geology and Geophysics
University of California
Berkeley, CA

C. ALLIN CORNELL
Department of Civil Engineering
Stanford University
Stanford, CA

PAUL C. JENNINGS
Division of Engineering and Applied Science
California Institute of Technology
Pasadena, CA

HIROO KANAMORI
Seismological Laboratory 252-21
California Institute of Technology
Pasadena, CA

KAREN C. McNALLY
Earth Science Board
University of California
Santa Cruz, CA

PETER H. MOLNAR
Department of Earth and Planetary Sciences 54-712
Massachusetts Institute of Technology
Cambridge, MA

PAUL G. RICHARDS
Lamont-Doherty Geological Observatory
Palisades, NY

ROBERT B. SMITH
Department of Geology and Geophysics
University of Utah
Salt Lake City, UT

Ex Officio Member

KEIITI AKI
Department of Earth and Planetary Sciences 54-526
Massachusetts Institute of Technology
Cambridge, MA

Liaison Members

LEON L. BERATAN
Chief, Earth Sciences Branch
Division of Health, Siting and Waste Management
U.S. Nuclear Regulatory Commission
Washington, DC

WILLIAM J. BEST
Directorate of Physical and Geophysical Sciences
Air Force Office of Scientific Research
Bolling Air Force Base
Washington, DC

JOHN R. FILSON
Chief, Office of Earthquake Studies
U.S. Geological Survey
Reston, VA

LEONARD E. JOHNSON
Program Director for Seismology and Deep Earth Structure
Division of Earth Sciences
National Science Foundation
Washington, DC

JAMES F. LANDER
Deputy Director, National Geophysics and
  Solar-Terrestrial Data Center
Environmental Data and Information Service
National Oceanic and Atmospheric Administration
Boulder, CO

Staff

JOSEPH W. BERG, JR.
Executive Secretary
Committee on Seismology
Commission on Physical Sciences, Mathematics, and Resources
National Research Council
Washington, DC

ROY E. HANSON
Senior Staff Officer
Committee on Seismology
Commission on Physical Sciences, Mathematics, and Resources
National Research Council
Washington, DC

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Department of Geosciences
Geophysics Program
Pennsylvania State University
University Park, PA

THOMAS C. BACHE
Program Manager
Geophysical Sciences Division
Defense Advanced Research Projects Agency
Arlington, VA

JOHN N. DAVIES
Geophysical Institute
University of Alaska
Fairbanks, AK

WILLIAM L. ELLSWORTH
U.S. Geological Survey
Menlo Park, CA

E. ROBERT ENGDAHL
Branch of Global Seismology
U.S. Geological Survey
Denver, CO

WALTER W. HAYS
Office of Earthquake Studies
U.S. Geological Survey
Reston, VA

ROBERT B. HERRMANN
St. Louis University
St. Louis, MO

JEFFREY K. KIMBALL
U.S. Nuclear Regulatory
Washington, DC

ANDREW J. MURPHY
U.S. Nuclear Regulatory
Washington, DC

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Rondout Associates
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U.S. Geological Survey
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PREFACE

Seismographic networks collect the data fundamental to the science of seismology, providing recordings of ground motion from natural earthquakes and other seismic sources ranging in size from the great earthquakes to the smallest detectable microearthquakes. This ground motion reveals the passage of seismic waves through the earth, and the waves may be recorded very close to the source or at great distances many minutes or hours after the event, having traversed paths that penetrate the entire earth. The data tell us much about the earth's interior structure and dynamics in addition to the nature of earthquakes. They allow identification of the type of source, explosion or earthquake, and they provide details of the seismic source process. These observations are important not only to the science of seismology but also, directly or indirectly, to society. For example, the earth's magnetic field--the basis for navigation, for geophysical exploration, and for a geological time scale--is generated mainly in the core, the structure of which is determined seismologically; the differentiation of explosions and earthquakes by seismic means is basic to monitoring a nuclear test ban treaty; seismic means are used to study inhomogeneities in the earth's mantle, which can lead to the discovery of mineral resources; the mitigation of seismic hazards for general construction and for critical facilities requires knowledge of both the locations of expected earthquakes and the nature of strong ground motion; and the search for methods of earthquake prediction relies heavily upon the existence of networks of closely spaced seismographic stations.

Seismology is a young and vigorous science, and it is being called upon continually to address new problems. The laboratory of seismology is the earth, its data base constantly changing and its time scale set by geodynamic processes. The seismographic networks are the basic scientific tools, analogous to major telescopes in astronomy or particle accelerator facilities in physics, that provide the continuing data base for the science. It is very important, for this reason, to keep U.S.-supported seismographic networks in the best operating condition, to provide networks with the latest technology, and to improve constantly the management and data bases of the networks.

These needs, unfortunately, have not always been met. The importance of observational data from seismographic networks has not been recognized consistently by decision makers allocating funds among competing programs. The various governmental agencies responsible for network operations encounter many difficulties in obtaining adequate funding for the maintenance, upgrading, and the research associated with these important national facilities. Even though the amounts of money needed are modest, crises in support funding seem to occur regularly, as short-term objectives change within the agencies.

Unlike the otherwise analogous telescope or accelerator facilities, seismographic networks are made up of large numbers of individual, relatively small installations, necessarily distributed widely with respect to the features studied, and thus globally for many investigations.

The broad perception of networks as facilities is consequently lacking, contributing to their vulnerability in times of financial stress. In addition, the ongoing process of upgrading involves simultaneous acquisition of new equipment for all stations in the network, including foreign installations in the global networks, and the consequences of this peculiarity in facility maintenance are not readily accepted by funding agencies. Given the extremely rapid rate of technological advance in the areas of data acquisition and processing, maintaining state-of-the-art capabilities in the seismographic networks is a difficult task indeed.

This report is the result of a workshop convened at the request of several governmental agencies to review the status and associated problems of and the outlook for seismographic networks. Recommendations have been made to help solve the problems and to assure a viable observational capability for the future. If this is accomplished, the time and effort of the many contributing scientists will have produced a major contribution to the nation.

Thomas V. McEvilly
Chairman

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CONTENTS

EXECUTIVE SUMMARY

An earthquake produces seismic waves, which radiate from its focus, traveling around and through the earth, with size and persistence proportional to the dimensions of the source. Only a very few of the thousands of earthquakes cataloged annually affect mankind directly. Most are perceptible only to seismographs--the scientific eyes and ears of the seismologist. From the seismograms, which display ground motion associated with the passing waves, comes our knowledge of the global distribution of earthquakes, of the internal structure of the earth, and of the earthquake source process. Interpreting the recorded seismogram requires sophisticated analysis procedures. Recent advances in analytical methods and instrumentation have increased dramatically the information to be gained from seismograms, but acquisition of adequate seismological data requires wide coverage by seismographs, globally, nationally, and regionally. Instruments must be maintained and upgraded regularly with the latest technology. Effective management is crucial for operations and data handling. All of these needs require adequate financial support over long periods of time.

Seismographic networks provide data essential to programs such as the mitigation of earthquake hazards, the definition of geological structure on the margins and within tectonic plates, the safe siting of dams, power plants, and other critical facilities, and the investigation of dynamic processes of the earth. Operating a typical seismographic network is not overly expensive, but it does require dedication of time and talent by seismologists who run the stations. In many cases the major rewards are in providing data to help solve problems of national and global significance.

The large number of questions on seismographic networks brought in recent months to the Committee on Seismology is strong evidence that there are critical problems with network operations. At the Workshop on Seismographic Networks, prompted by these questions, participants considered global, regional, and national networks collectively as an integrated system and also as entities with specific problems. This report discusses each component of the system in terms of rationale and problems, giving recommendations for solutions. A brief statement follows of major problems and major recommendations for the global, regional, and national networks.

Global Networks. Global networks are expected to provide for the scientific community a data base that continues indefinitely. Unfortunately, managing agencies find it difficult to recognize this long-term scientific importance. The service function of the networks, i.e., providing data for other users, must be considered in funding decisions by the managing agency. Global networks require continuing financial support at an adequate level. It is recommended (1) that consideration be given to transferring management responsibility for the global network from its present organizational base to another location within the U.S. Geological Survey or even to another agency, if such a change seems clearly advantageous; (2) that stable funding for global networks be sought from normal budgetary requests from within the U.S. Geological Survey, from the Defense Advanced Research Projects Agency, and from other agencies that use data from the networks; (3) that access to digital data and use of those data be improved while networks continue to meet fully the demand for and the global coverage provided by analog (i.e., visible) data at the present time; and (4) that procedures be established and funding be provided for the orderly and continuing interagency transfer of the most recent instrumentation and technology.

Regional Networks. Regional network operations are beset with problems falling into three categories: functional definition, funding difficulties, and operational problems. Functional definition is the planned lifetime of a network, and a realistic estimate of it needs to be provided. Funding difficulties are of two types: a lack of stability on a year-to-year basis, and the vulnerability of research funding being decreased to maintain network operations in times of fiscal stress when research funding is mixed with basic operational costs of the network. Operational problems are seen in a lack of coordination among networks, the need for a more standardized data base management system, and a growing obsolescence of network equipment. These problems are interrelated and difficult to order in importance.

Recommendations are (1) that networks of planned, limited lifetime be reviewed every three to five years with respect to objectives and performance; (2) that the provision of data fundamental to research on seismotectonic processes and earthquake occurrence in the region be acknowledged by funding agencies as the main purpose of regional networks; (3) that an adequate data set from all regional networks be archived; (4) that data formats be standardized; and (5) that operations of networks be coordinated.

National Network. The concept of a national network lacks general acceptance and widespread support by the U.S. seismological community, within which there is at present little coordination of network operations. The concept is sound, and support will grow with formulation of a suitable plan for implementation.

Working Group on Seismic Networks. It is recommended that a Working Group on Seismic Networks be set up under the Committee on Seismology to provide continuity and uniformity in consideration of the various policy matters arising in network seismology. This group will provide the review functions recommended throughout this report for global, regional, and national networks. It should evaluate continually the health and status of regional networks, and advise on the development of a national network.

The contributions to the earth sciences from seismic networks of all types have been substantial in the past two decades. We have entered the 1980s with major advances in data acquisition, management, and processing techniques now available to seismology. The challenge is to build effectively on the present structure of networks, creating a new capability for addressing the next level of difficulty in the exciting problems of geoscience.

INTRODUCTION

The Workshop on Seismographic Networks was convened to consider the problems confronting network seismology and to provide scientific, technical, and management guidance to federal agencies, primarily regarding the operation of global, national, and regional seismographic networks. It was prompted by a number of related questions brought in recent months to the Committee on Seismology. This report is the result of that workshop.

The National Research Council report, U.S. Earthquake Observatories (NRC 1980), recommended establishing an integrated U.S. Seismograph System (USSS), the core of which would be a new national network of modern digital seismological observatories. The report called also for a guiding working group on the USSS to be established. Many of the problems discussed and several recommendations in this report are similar to those in the 1980 study. Current constraints in federal funding, the potentially disastrous budget cuts nearly imposed in earthquake studies by several agencies in the fall of 1981, and the promise of continued stringencies all impart a sense of urgency to the need for clear position statements by the seismological community on U.S. seismographic networks.

The global, national, and regional systems of seismographic stations, spanning the earth much like meteorological observatories, provide the fundamental data base for scientists to investigate the earth at different scales, addressing problems of earthquake hazards and prediction, safer sitings for critical facilities, and the identification of underground nuclear explosions, in addition to fundamental questions on the physical and chemical composition and geological structure and dynamics of the entire earth. Major advances in the earth sciences have come directly from these data. Agencies with responsibilities for maintaining subsets of this worldwide seismographic system have asked the Committee on Seismology for guidance in allocating their fixed or decreasing financial resources among competing scientific efforts.

As the primary source of seismological data, networks have been and continue to be essential to the scientific health of seismology. The committee perceives a range of serious problems threatening this data base. The global network is insufficiently funded. All networks suffer from rising operational costs. Questions must be addressed on appropriate operational lifetimes. Much instrumentation is obsolete. Modernization of data acquisition and archiving methods is needed, and existing new approaches to data base management should be introduced to provide a creative environment for research. It is generally acknowledged that digital systems must ultimately replace analog, but at what cost? All of these efforts call for increased financial support at a time when the funding climate is inhospitable. The seismological data base demands stable continuity of support for operating networks that is independent of variations in research support.

An important aspect of this report is the consideration, perhaps for the first time in such depth, of the interplay among the network systems of differing scales and purposes--global, national, and regional--and their definition as a major scientific resource for acquisition of important data. In this unification the national network becomes the linkage by which regional networks are integrated with the global seismographic systems. Thus, that portion of the global network located within the United States can be viewed as a subset of the national network, which in turn is a subset of stations from regional networks. The rationale for such a structure is to facilitate exchange of data, methods of analysis, and scientific results, by enlisting the involvement of present network operators in the system.

In order to review in depth the present state of difficulties facing the networks, the committee solicited assessments and opinions from a range of network operators, users, and supporting agencies. A comprehensive questionnaire was formulated and distributed to operators of regional networks. Forty-five completed questionnaires were returned by federal and state agencies and universities, providing an unprecedented and substantial overview of regional seismographic networks operated for a variety of purposes by U.S. scientists. Appendix B gives the questionnaire, a list of the respondents, and a summary of the resulting information.

Even before the workshop began, the need for a continuing working group that would address practical problems of seismic networks from a perspective different from that of any one agency was recognized. The Committee on Seismology plans to establish a working group on seismic networks within the National Research Council, for if it does not, the committee's agenda for years to come will be dominated by network questions. The working group will be asked for policy recommendations on the interrelationships among global, national, and regional networks. Other, more specific, questions for the working group are given throughout this report.

The working group, which will report to the Committee on Seismology, is to consist of at least five individuals with overlapping terms of about five years. Network problems are not quickly solved. It is therefore important for a majority of members of the working group to serve long enough to show some results from changes in network policy. We anticipate that the working group will often need to seek the advice of specialists, particularly in recommending technological improvements.

The report considers global networks in Chapter 3 and regional networks in Chapter 4, reviewing the nature and use of each, identifying the problems peculiar to each, and recommending various approaches toward solutions to the problems. Chapter 5 reviews the concept of a new national network and its place in the present network structure. By virtue of the variety of issues, the recommendations range from specific actions to acknowledgments of remaining outstanding difficulties requiring further attention. Background information for the workshop is presented in Appendixes A through C.

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GLOBAL NETWORKS

REVIEW

The history of global seismographic networks* is closely tied to the U.S. national need for improved capability in detecting and identifying underground nuclear explosions. The World-Wide Standardized Seismograph Network (WWSSN) was established in the early 1960s as a part of Project Vela Uniform, a program of fundamental and applied research in seismology managed by the Defense Advanced Research Projects Agency (DARPA). Since then DARPA has been responsible for virtually all advances in global seismographic networks, but has declined to commit funds for routine WWSSN operations. Key elements of the WWSSN are standardized three-component long- and short-period seismographs with uniform calibration, and the means for distributing the seismograms to the earthquake research community. The WWSSN today comprises 110 stations operating in 54 countries; its role is to produce the data needed for fundamental research in seismology. The responsibility for installing and managing the WWSSN was assigned by DARPA to the U.S. Coast and Geodetic Survey (USCGS). The network was essentially completed by 1963. The WWSSN serves as a worldwide organization base to which network improvements and modernization can be applied. The network was partially funded by the National Science Foundation (NSF) between 1968 and 1978. In 1973 the WWSSN and other elements of the USCGS earthquake program, apart from the data services, were transferred to the U.S. Geological Survey (USGS) and,

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*See Appendix A for further information on the global networks.

since 1978, the network has been funded entirely by the USGS under the National Earthquake Hazards Reduction Program (NEHRP). Since the inception of the WWSSN, more than 5 million original seismograms have been microfilmed and 60 million high-quality film copies have been supplied to research workers by the Environmental Data Service of the National Oceanic and Atmospheric Administration (NOAA). Despite the superiority of the more recently available digital seismic data for many purposes, the analog seismograms from the WWSSN remain the foundation for much fundamental seismological research, not only in the United States but around the world. WWSSN encountered its first difficulty when attempts were made to transfer its financial support from the Department of Defense (DOD) to NOAA in the late 1960s, a transfer that had been discussed and coordinated over a period of years. Opposition centered on the U.S. support of the foreign stations of the WWSSN, and the NSF assumed the responsibility for partial support of the foreign stations of the WWSSN in 1968.

In the late 1960s, DARPA sponsored the development and installation of 10 high-gain long-period (HGLP) seismographs. The HGLP seismographs were superior to the WWSSN seismographs in the detection of long-period earth motion because of their installation in special airtight tanks to protect them from temperature and pressure changes. The HGLP seismographs were also the first globally deployed seismographs to be equipped with digital recorders. The USGS was assigned responsibility for the HGLP network and managed it as a complementary part of the WWSSN. Later, five of the HGLP systems were modified: short-period seismometers were added, and the original digital recorders were replaced by more advanced, computer-controlled versions. The modified HGLP seismographs, now called Abbreviated Seismic Research Observatory (ASRO) systems, are still in operation.

The HGLP seismographs, especially the horizontal components, are affected by earth tilt caused by atmospheric loading of the earth's surface by wind and variations in barometric pressure. The resulting ground noise is attenuated rapidly with depth. A joint effort by private industry and the government led to the successful development of a broadband low-noise force-balance accelerometer that could be installed in a small-diameter borehole. Operated at a depth of 100 m, the borehole seismometer is virtually unaffected by wind noise at the surface. In 1973, the USGS, with DARPA funding, began the development and global deployment of 13 Seismic Research Observatories (SRO) that combined the new borehole seismometer with an advanced analog and digital recording system.

The availability of high-quality digital data produced by the SRO stimulated utilization of digital data by many research organizations. New analytical techniques and software were developed, opening exciting new directions of research such as the determinations of source parameters for all large earthquakes in a given time interval. In the late 1970s, again with funding from DARPA, the USGS developed a digital recorder that could be attached to existing WWSSN systems. Seventeen such recorders are currently being installed at WWSSN stations (termed DWWSSN stations). NSF has funded their installation at six foreign stations, and the USGS is funding installation at the remaining sites.

ASRO, SRO, and DWWSSN stations have been termed collectively the Global Digital Seismograph Network (GDSN) and observatories are located in Figure 1. The GDSN and the WWSSN are complementary networks and together have been termed the Global Seismograph Network (GSN). Operation of the GSN, with stations in more than 60 countries of the world, is a notable example of successful international scientific cooperation and data exchange. Hundreds of seismographic stations are operated by other countries that go into a total global seismographic network effort, and data from these are available to U.S. seismologists. There are many seismologists, both in the United States and in foreign countries, who do not have access to computer facilities and can work only with analog data, who prefer to work with analog data, or who need the denser global coverage of stations provided by the WWSSN. In its relatively short life, the WWSSN has generated an historical data base that is important as a baseline for testing new hypotheses; continuing data from many of the same stations are essential to eliminate the possible effects of station location on recordings of seismic events. The GSN would continue an infrastructure that stimulates and supports international cooperation in seismology. It now provides the USGS with convenient and ready access to seismological organizations in more than 50 countries. In many countries, the GSN stations represent the principal or only national facilities for support of in-country seismological programs. Termination of some WWSSN stations may have serious and long-lasting

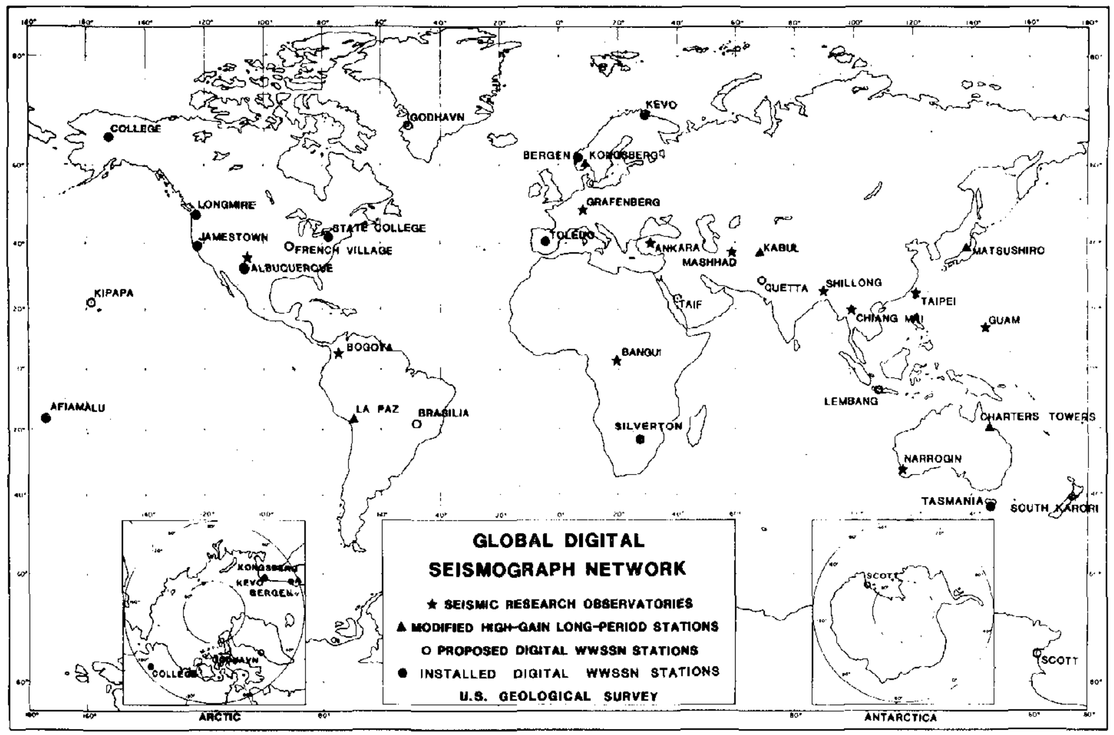

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FIGURE 1

political as well as scientific repercussions. Even though numerous seismographic stations exist in many other countries, their data are not as readily available to the researcher as are GSN data because of the established data distribution system.

While the SRO systems were being installed, the University of California at San Diego developed and began installing digitally recording gravimeters that are designed to record very-long-period vertical-component seismic data, including earth tides and free oscillations. Seventeen are currently in operation, and the network is called the International Deployment of Accelerometers (IDA). The digital data provided by the IDA network and distributed by NOAA are used by many research groups for very-long-period studies of the earth's structure and the earthquake source mechanism. Implementation of IDA has been funded by the National Science Foundation and a private source, but, as manager of GSN, the USGS has been suggested by NSF as the agency that can best provide long-term future support for the network.

The role of DARPA is limited to the development and demonstration of new technology; hence DARPA support for the operation of the GDSN ended in FY 1979 even though much DARPA-supported research today makes substantial use of GDSN data. Following recommendations set forth in the NRC reports entitled Trends and Opportunities in Seismology (NRC, 1977b) and Global Earthquake Monitoring (NRC, 1977a), the research community strongly urged that the USGS provide long-term operational support of the GDSN beginning in 1980. Funding for the continued operation of the network by the USGS was planned in the report entitled Earthquake Prediction and Hazard Mitigation: Options for USGS and NSF Programs (NSF, 1976), which outlines the structure of the National Earthquake Hazards Reduction Program (NEHRP), beginning in FY 1980 under all budget options in the report. The recommendations were accepted, and, beginning in FY 1980, the USGS has provided both management and funding of the GDSN.

Network support operations are managed by the USGS Albuquerque Seismological Laboratory (ASL). ASL furnishes operating supplies routinely and replacement parts or components on call and repairs defective equipment returned from the stations. Contract maintenance technicians operating out of ASL install new equipment and service operating stations. Optimally, two or three maintenance teams are overseas at any given time and can respond to provide assistance to stations. During routine service visits, the maintenance personnel perform tests, calibrations, and any software or hardware modifications that are required. In operating the WWSSN stations, participating organizations contribute 2 to 3 times more than the annual costs to the U.S. government.

The most recent (to 1982) development has been the installation of a five-station telemetered network by Sandia National Laboratories as part of a Regional Seismic Test Network (RSTN). The stations, which are unmanned, acquire signals from borehole seismometers (improved versions of the SRO sensors) and transmit nine channels of data continuously in three data bands: short-period, mid-period, and long-period. A geosynchronous satellite provides two-way communication between the network control station, located in Albuquerque, and each RSTN station. Current plans are to merge RSTN data (events only in the case of short- and mid-period signals) with GDSN data on the network day tapes for general distribution. RSTN data are also received and processed in the new DARPA Center for Seismic Studies (CSS) in Arlington, Virginia.

The establishment of the WWSSN, and its subsequent development, was certainly one of the outstanding U.S. accomplishments in international support of science. It has been the major factor in developing seismology into a quantitative and precise science that provides much of our basic knowledge of the earth's structure, of the active processes that deform it, and of the hazards and risks of earthquakes. One can well argue that the revolution in the earth sciences that followed the recognition of plate tectonics derived from two main subfields, i.e., marine geology and seismology, and that the contributions from seismology derive largely from an analysis of WWSSN data. We have every reason to believe that advances in the coming decades will flow similarly from analyses of data from today's global networks.

ASSESSMENT OF PROBLEMS

Global networks have been plagued throughout their existence by the lack of sufficient long-term funding from a host organization within which the operation is viewed as a significant element and thus receives enthusiastic support. The funding problems of the WWSSN did not cease with its transfer to the new Branch of

Global Seismology of the USGS in 1973. It now had to compete for its funding with other elements within the USGS of the large and underfunded NEHRP, and with the increasing support needed for the GDSN. Global networks, in the competition between USGS service- and mission-oriented programs, have been subject to funding pressures that annually threaten their stability and continuity. Within the broad USGS seismological research program, a fairly small fraction of scientists works with data from global networks, so that internal advocacy, while dedicated, represents a minority. Consequently, the maintenance of global networks, an important service to the seismological community, lacks universal support within the Survey. Despite this situation, USGS continues to support the GSN. In contrast, a large part of university-based seismological research on the earthquake process, earth structure, tectonics, and earthquake prediction relies heavily on the global networks. Thus many non-USGS seismologists depend upon that agency for service in providing high-quality global data while most USGS seismologists do not need such data for their research. This dichotomy produces competition between programs with strong Survey interest and those that provide services largely for non-Survey personnel. Nevertheless, USGS administrators have allocated funds for the maintenance of the WWSSN and to allow for the steady upgrading of the worldwide system by the addition of a digital capability, with support from DARPA and NSF.

A serious problem exists in that global network funds have remained fixed for the past three years. This year, once again, the seismological community and the USGS have been faced with options to meet the budget ceilings.* These include reducing WWSSN, reducing GDSN, and obtaining more funds, the latter never succeeding despite strong efforts. The community has always reaffirmed its strong backing for retaining the capabilities represented by the WWSSN essentially as it now exists. This annual occurrence makes it clear that some means must be found to ensure the continuity of the WWSSN and its systematic upgrading into the digital era.

The GSN should be insulated from the vagaries of funding of the NEHRP. Support for the GSN must be thought of in terms of decades and in terms of its international impact and in terms of the health of seismology. The

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*See Appendix A for details of global network options.

USGS must continue to meet its long-term commitment to the GSN, even if the NEHRP should be terminated. Given the time scale of processes controlling global seismicity, it is essential to establish and maintain a data base that is uniform for many decades.

The major short-term problem thus rests with funding for the global system. Because of recent increases in the costs of supplies for the WWSSN and of maintenance required for the GDSN, it is becoming increasingly difficult for the USGS with inadequate program resources to maintain the present and the projected level of operation of these networks. On the other hand, diverse users in the seismological community require both analog and digital data with no interruption of continuity or coverage of either type of data. Eliminating either the WWSSN or the GDSN should not be considered an acceptable solution to current funding problems. (Absorbing a FY 1983 $500,000 shortfall in this manner would represent a 35 to 40 percent reduction in the data collected.)*

Seismologists do not consider the problem as one of analog versus digital data. Until very recently, analog seismograms constituted the fundamental data base of global seismology. Although analog records are more limited in dynamic range and more difficult to use for quantitative analysis than digital records, they appeal to the trained eyes of seismologists and other earth scientists more directly. Very often subtle changes in the waveform on analog records are used for the determination of the depth of earthquakes and for information on the fine structure of the earth's interior. Initial hints that led to important discoveries have often been found in such features of analog seismograms. Analog records represent many more stations than digital records, and they can be utilized without sophisticated hardware and software.*

Digital seismograms, on the other hand, are far superior to their analog counterparts when we know what parameters are to be extracted from them. A large number of data can be processed in a relatively short time to obtain accurate results. Over the past few years, the number of high-quality normal mode data and source mechanism solutions has increased by more than an order

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*See Appendix A for budgetary information.
**See Appendix A for a discussion of the utility of analog data.

of magnitude, which brought about several major breakthroughs in seismology. The basic fact of data superiority assures the ongoing conversion to digital acquisition of seismic data.

The importance of the global data base to the seismological community is such that the overwhelming consensus of the workshop participants was that no stations should be eliminated with the possible exception of redundant WWSSN analog and GDSN digital stations. It is anticipated, however, that digital stations will eventually supplant the analog WWSSN stations at selected sites of the global network and that analog (microfiche) seismograms will be generated from the digital recordings. The remaining analog WWSSN stations should continue to operate until it can be demonstrated to the scientific community that they are no longer needed as part of the global data base.

A third type of problem lies in the slow pace of utilization of the digital data. Because of the diversity of users and their in-house capabilities, there are difficulties in the transfer of technology in going from analog to digital recording. This includes instrumentation changes, software development for users, and dissemination of information to users. Moreover, the flow of digital data to users is not yet adequate. Tutorial data packages on selected special events are needed, to allow researchers to gain experience with the new data at reasonable cost and to learn how to use them for their individual problems.

High-technology, high-cost facilities transferred from one government agency to another create a fiscal problem for the receiving agency. We here refer to such transfers as that of the WWSSN from DOD to NOAA to the USGS; that of the SROs from DOD to the USGS; the pressures for transfer of IDA from NSF to USGS; and the possibility of a transfer of RSTN from DOE to USGS. The problem is not that the receiving agency is surprised by an unexpected request--in the above cases, transfers have been planned over a period of years. Rather, the problem is that base funding is almost never transferred along with the responsibility for the facility operation. The receiving agency thus gets the funding problem as part of the transfer. It should be emphasized that these transfers are usually regarded as the best alternatives to the government and to the science. The option of dismantling a valuable resource is not an acceptable alternative.

RECOMMENDATIONS

It is essential to maintain a global data base that is uniform for years or even decades. This requires establishing a supportive home environment for GSN. Relevant U.S. government agencies must realize that a long-term commitment is implicit in the very existence of GSN, independent of the mission-oriented programs of the host organization. We suggest that a solution to the long-term problem may be to transfer responsibility for the global networks from its present NEHRP base to another location within the Survey or even to another agency so the GSN does not compete directly for funds within a largely unrelated program.

In regard to the options open to the USGS over the short term, we recommend seeking funds to support the global networks at the required level from normal budgetary requests, from within the USGS, and from other agencies, such as DARPA, that use data from the networks. Should this fail, we recommend that efforts be directed toward maintaining the WWSSN at the present level at the expense of a slowdown in the completion of the GDSN program and of a data loss that may result from a reduced GDSN maintenance program. Consequences of this approach should be reviewed yearly. At the same time the USGS should seek assistance from other agencies in providing operational support during this difficult interim period. In particular, DARPA cannot ignore the pertinent role of the GDSN data base in DARPA objectives, and the serious degradation threatened by inadequate funding.

The problem of digital data usage must be addressed while the demand for analog data continues to be met fully. Additional efforts are needed to familiarize seismological researchers with the use of digital data and associated software for analysis. Digital data will ultimately replace the analog WWSSN. Methods for better access to the data need to be developed, and new data products at reasonable cost to the user should be generated and provided by agencies responsible for data distribution to promote wider use of the data.

The interagency transfer of network facilities is a remaining outstanding issue. The associated problems can be largely resolved if adequate funding is transferred along with the operational responsibility, as was done, for example, in the recent transfer of the strong-motion network from NSF to USGS.

4

REGIONAL NETWORKS

REVIEW

Regional networks are those that have been installed to study seismological problems on a geographic scale of 100 to 1000 km. Such networks have been established widely in recent years, and today there are approximately 50 regional networks in the United States, each consisting of tens to hundreds of individual seismographic stations. These networks are supported by a number of different groups (e.g., USGS, U.S. Nuclear Regulatory Commission (USNRC), DOD, DOE, and other federal, state, and local agencies) for a number of different reasons.

The role of regional networks is, in general, to delineate the time and space distribution of earthquakes on a fine enough scale to contribute to our scientific understanding of earthquake occurrence and related tectonic processes and to provide important baseline data for engineering investigations (e.g., earthquake prediction and hazard assessment). Figure 2 shows the earthquake occurrences in California for 1980. U.S. regional networks date from the 1887 installation of the University of California seismographic stations.

The first telemetered network in the U.S was that of the USGS in Hawaii. Developed during the mid-1950s, the network had four original stations around the summit of Kilauea Volcano with the information telemetered to the Hawaiian Volcano Observatory. By July 1958 this local network had expanded to about 15 km across.

An early U.S. regional network of seismographic stations that was connected by FM telemetry to a central site was installed by the University of California at Berkeley in 1960 to monitor and study seismicity in central California. Regional networks with increased

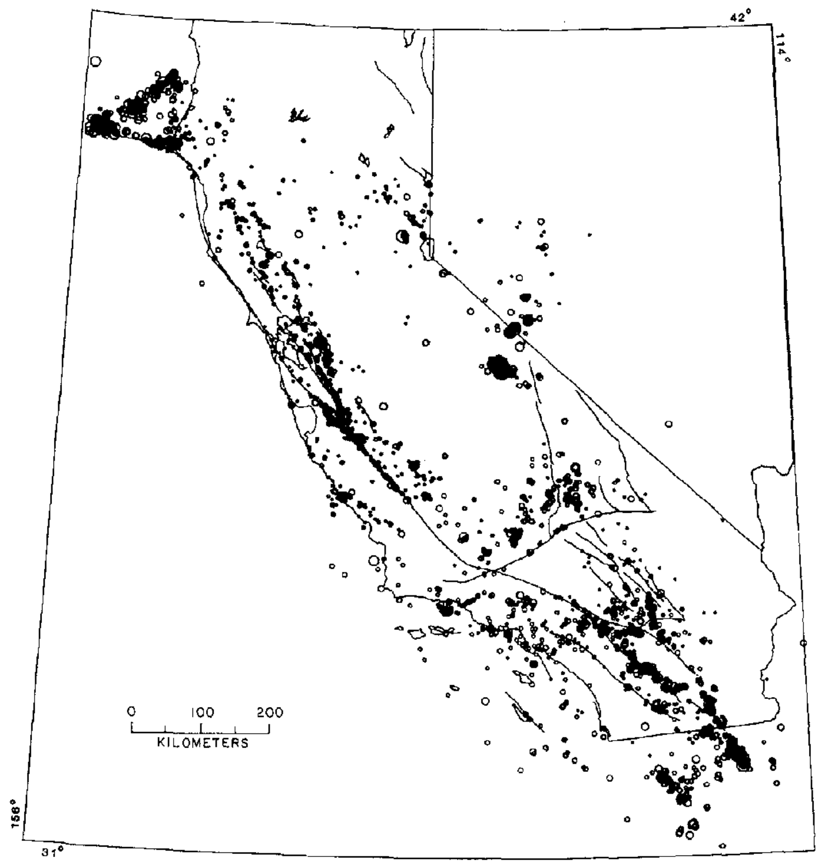

FIGURE 2 California seismicity for 1980 from data of three regional networks - Caltech, Univ. of Nevada, and USGS.

station density were installed by the USGS in the late 1960s to study in greater detail the San Andreas Fault in California. Within a very short time, well-defined spatial patterns of earthquakes were delineated, providing a clearer fine-scale picture of the spatial distribution of earthquakes. Given this initial success, throughout the next decade, regional networks were extended in California and established in other states with ongoing seismicity.

Only since 1970 or later have the major seismological problem areas of the United States been consistently monitored at high sensitivity by regional networks. The increase in data flow resulting from this large number of seismographic stations has, in part, been managed by the introduction of automatic detection and digital data processing. The acquired data have been used for engineering planning, disaster mitigation, and fundamental scientific investigations. In many cases the results of a network installation and operation transcend the original purpose of its installation. Some relatively small networks have contributed important scientific results on topics ranging from plate tectonics to the mechanics of crustal deformation and from induced seismicity to the prediction of volcanic eruptions.

The proliferation of regional networks, usually funded initially by various mission-oriented agencies for very specific purposes, has resulted in some problems. Coordination of the establishment, distribution, and shutdown of local and regional networks has proved to be a difficult task. An increasingly acute problem for the USGS is its role in continuing the operation of networks that have lost support from their original funding agency, and the impact upon other USGS programs if financial support is provided.

The prime reason for this workshop was a perceived need to assess the future of regional networks in terms of federal agency funding constraints in late 1981. The particular trigger was the threatened budget cuts in the fall of 1981 that could have decimated this vital data base. Important decisions are being made now on the 1983-1984 network funds. This report marks the first time that the activities and problems of regional networks have been examined inclusively. The basic background data were obtained from a thorough questionnaire used by the committee to obtain data and opinions from the responsible operators of some 45 regional networks. The collected information helped in the assessment of the problems and the formation of the recommendations that follow.

ASSESSMENT OF PROBLEMS

Given that there are more than 1600 U.S. seismographic stations grouped functionally and operationally into 50-odd independently managed networks, with funding coming from about 10 different federal agencies, an equal number of states, some cities, utilities, and even private universities, it is not surprising that there are problems in regional network seismology. Mixed with this basic diversity of purpose and support are the particular goals of the operators, usually established research scientists with their own perception of purpose for the network they manage.

The committee, in considering agency questions and operators' comments, has defined a number of problems facing the regional networks. They fall into three separable categories: functional definition, funding difficulties, and operational problems. A functional definition, that is, a clear statement of network goals and a realistic estimate of its planned lifetime, must always be provided. Funding difficulties are of two types: a lack of stability on a year-to-year basis and the vulnerability of research funding being decreased to keep networks operating in times of fiscal stress when research funding is mixed with basic operational costs of the network. Operational problems are seen in a lack of coordination among networks, the need for a more standardized data base management system, and a growing obsolescence of network equipment. These problems are interrelated and difficult to order in importance. A robust funding environment would go far toward solving most of them. Unfortunately, such is not the present situation. We consider these problems now in turn.

A significant part of the overall problems of regional networks is the difficulty of designating a realistic design lifetime of a particular network. It is a well-recognized fact that some networks are operated to provide a specific data base and that when that data base has been collected the network is expendable to the supporting agency.

There are a number of support agencies that are mission-oriented, serving either a regulatory or a service function for the government as contrasted to a research function. In addition, there are agencies that represent a gradation between functions. The USNRC and the U.S. Army Corps of Engineers might be taken as examples of the former, whereas the USGS is an example of an agency in the middle ground, serving both a service and a research function.

The particular mission of the support agency has a definite controlling influence on the design lifetime of a network. While it may seem appropriate to operate a small regional network in the immediate vicinity of a proposed critical facility to obtain seismological data for design purposes, any such window of data must be recognized as a very short-time sample of natural phenomena that occur infrequently. Furthermore, the facility itself may alter the seismological characteristics of the site, as in the impoundment of a large reservoir.

Some regional networks such as those in California supported by the USGS or those in the Northeast and Southeast supported by the USNRC are intended to provide seismological data over a very broad region--not specifically for a particular site. Such regional networks may require a minimum of 15 to 20 years to obtain a representative sampling of seismicity.

Clearly, an initial understanding of design lifetime is important, as well as a regular evaluation of the initial plan in light of the results of operating the network.

Perhaps the most significant problem perceived by networks is the lack of a rational approach to stable network funding. Many operators attribute this situation to a lack of realization at high levels in support agencies that many of the applied and basic research problems addressed by regional networks require long and continuous data bases. Operators see vagaries in funding as a result of this situation.

Separation of the research activities from the operation of regional networks appeared as a common theme in the non-USGS operators' responses to the questionnaire and leads to our identifying the following problem: for funding purposes the operation of a network (all steps through bulletin preparation) is often lumped together with research (the scientific analyses of the network data). In times of financial stringencies, we thus see elimination of research funds, since operational costs are fixed and subject to inflation. When the scientist in charge can cut only research funds in combined budgets, he assumes more and more the role of a technician providing services. Research and network operation are usually not evaluated by different standards, but they should be. For the former the standard is scientific merit, whereas for the latter it should be stability, quality, and service.

A related but specialized difficulty is seen in maintaining a balance of support for operations and network development between funding agency and funded operator when there is a joint responsibility for that network.

Lack of coordination appears as a generic problem that emerges in one fashion or another in the majority of the problems that confront the regional seismographic networks. Effects of a lack of coordination show up in the areas of data exchange, network boundaries, software compatability, data archives, and duplication of efforts in a number of technical developments, including both software and hardware. The net result has been to reduce the effectiveness of the regional network operations as a whole.

A class of problems involves the lack of standardized methods for data base management. This problem involves a number of elements, including data management, data centers, software portability, and manpower usage. Network operators customarily face two conflicting objectives. On the one hand, they contribute to an archive of data that can be used long-term, together with other geophysical data (perhaps including other seismic networks) for an overall synthesis. On the other hand, the scientist-operator must undertake (usually on a more short-term basis) scientific research objectives specific to the immediate field area, and drawing heavily on the data set.

There exists a need to achieve a standard set of regional seismographic network data that can be easily accessed by general users for both service and research purposes. We anticipate that the archive that is supplied by the aggregate of networks will constitute a major scientific resource for understanding seismicity patterns on a regional and national scale.

With respect to present scientific and technologic capabilities, regional networks suffer from obsolete equipment. The existing regional networks of seismic stations, including more than 1600 stations, almost universally employ short-period, vertical seismometers. Most of the signals from these instruments are transmitted by narrow bandwidth, low-dynamic range FM telemetry that was first employed more than 20 years ago. The seismograms obtained from these networks have proven to be an economical and effective scientific tool for solving problems of earthquake location and, to a limited degree, for defining their source mechanisms. However, these data are inadequate for analysis by many powerful seismological methods developed during the past decade, and the data consequently do not provide critically needed new information on earthquake source properties and the structure of the earth's crust. The problem is particularly acute in the regional networks located outside of California, where network station spacing is large, and in areas where there are few high-quality instruments of other types operating within the short-period vertical networks. The lack of higher-quality data not only affects the basic research capabilities of the networks, but also may compromise their potential for answering mission-oriented questions posed by funding agencies. Within California, for example, it may be argued that present coverage, with hundreds of obsolete short-period stations, could be replaced to economic and scientific advantage by fewer modern instruments.

RECOMMENDATIONS

There are no easy answers to the problems summarized above. It is probably not possible to assign rationally a priori a design lifetime to any but the most local, site-specific networks. On the other hand, initial guidelines must be set by funding agencies when a limited duration is planned. Problems of regional seismicity will not be "solved" in a three- or a five-year period. Rather, it will normally require lifetimes of decades to obtain a representative sampling of the seismicity. Nevertheless, networks of planned, limited lifetime should be reviewed on a three- to five-year basis so that the state of knowledge gained by operation can be weighed against the network purpose.

There exists a disturbing range of quality among regional network operations. Different networks currently operate to quite different standards. While some operators can produce on demand a bulletin updated to within a few days prior to a request for information, others have essentially no bulletin. Some produce seismicity maps with accurate information on magnitudes and focal mechanisms, but others have been operated with ignorance of instrument gain or polarities. The periodic review should involve the supporting agency or agencies and address a network's intended purpose and performance, considering all specific mission-oriented goals. A network should also be reviewed with respect to alternative approaches that implement new technology to achieve equal or better performance at comparable or lower cost. We believe also that all regional networks, regardless of size or funding source, should be reviewed by the same review panel.

There is, of course, no way to guarantee stable funding of regional networks. However, an irrational slashing of networks can be alleviated by an increased understanding of the broader role of regional networks by the funding agencies and by increased coordination of network operations at the national and local levels. Furthermore, the above review procedure can result in a firm commitment to support (or terminate) until the next three- to five- year review. Agencies have the responsibility to decide when a network has satisfied their needs and to arrange for an orderly closure. Since networks often involve other users (who probably are not sharing in support), these "shadow" users should be informed early of decisions to terminate. Exhibit 3 in Appendix B gives examples of the wide variety of such users for four networks. The mission-oriented support agencies should also recognize and carefully evaluate their role and responsibility to support a national network independent of their current needs.

We *recommend* that the network funding agencies admit to a realization that for most operators the main purpose of a regional network is to provide data fundamental to research on seismotectonic processes and earthquake occurrence in the region. This simple acknowledgment will allow open and rational discussion of the separate costs of routine operation versus research. A good faith effort must be made to remove the serious vulnerability of research support in the packaged funding practice. It will go far in eliminating different opinions between operators and funding agencies on true operational costs.

We believe that it is time to emphasize the archival function of regional networks. Minimum desired archived data include earthquake summaries, phase lists, and digital seismograms at some minimum magnitude cutoff. Network specifications, including station parameters and response characteristics, are necessary. This function can be used as the major distinguishing feature separating what we call a network from a portable array.

Of the 45 U.S. regional networks responding to the questionnaire, there are 11 that operate dedicated computer-based recording centers. Many of these centers were established with direct support from the USGS. These regional centers provide the beginning of a skeleton framework for a recommended system of U.S. Regional

Network Data Centers that should operate with standardized data formats that provide easily transportable data and that are well documented. A specific effort should be made to provide easy access via telephone terminal or equivalent to the developing Regional Network Data Centers.

Coordination is not easy, but the above initiatives will in effect force a semblance of coordination and cooperation onto the regional network scene. We contemplated a recommendation for a regional coordinator who would work toward a greater integration of operations in a given area. It seems best, however, to hope than an evolution toward Regional Network Data Centers will provide a natural focus for coordination among operators, users, and support agencies.

Seismologists throughout the United States are working on a variety of theoretical and operational software--at a great investment of manpower and money. Through an effective coordination among networks, duplication can be minimized and significant developments can be made available to the rest of the community on a timely basis.

Throughout the history of seismology in the United States, technical, theoretical, and observational problems have been tackled by seismologists. With the rapid expansion in seismological efforts and with advances in modern electronics, computation capabilities, numerical modeling, etc., it is cost effective to use experts in these fields to help solve seismological problems, and to disseminate the solutions, as a means of allowing seismologists time to pursue their own research.

There exists within the broad seismological community considerable expertise and experience in data collection systems other than those in common network usage. Such systems employ broadband sensors and wide dynamic range digital telemetry and recording. The opportunities presented by this technology are in many respects comparable to those apparent in 1960 when specifications were set for the worldwide standard seismograph network first proposed in 1959 by the Berkner panel. Several groups are proposing new generations of instruments, for various applications. It is important that input comes also from the regional networks on standardization and the type of recording and data collection systems to be used.

It is recommended that a standing working group be established by the Committee on Seismology (the same group that represents the seismological community on the problem of a national network--a problem that is closely interrelated) to evaluate continually the overall health and status of regional networks. This working group would provide all the review functions recommended for regional networks in this section. It would work closely with the network operators and with agencies that fund the network and provide advice on related matters. Most such agencies were represented at this workshop, and their representatives indicated a need for ongoing review of the type recommended here.

5

NATIONAL NETWORKS

REVIEW

The rationale for and a proper design of a state-of-the-art national digital seismic network were the subject of a comprehensive report prepared by the Panel on National, Regional and Local Seismograph Networks of the Committee on Seismology entitled U.S. Earthquake Observatories: Recommendations for a New National Network (NRC, 1980). The major conclusions and overall recommendations from that report are included as Appendix C. Many of the recommendations set out in this report parallel closely those in the 1980 report. This chapter considers those 1980 recommendations in the context of global and regional networks, and in light of the current funding picture.

U.S. seismographic networks were considered on a national basis, and it was recommended that a concept be adopted of an integrated U.S. Seismograph System (USSS) so that the effect of damaging earthquakes on long-term national economic and security matters could be properly assessed and ameliorated. This application represents only a part of the overall role of the USSS, which would be a basic research tool in a variety of seismological investigations such as the detection and location of seismic events, studies of earth structure and processes, and site evaluations for critical facilities. The USSS is perceived to be a national and integrated system consisting of

1. a national digital seismograph network
2. regional networks
3. data archiving and dissemination functions
4. management function including (a) a working group

guiding the development of the USSS and (b) a working group on instrumentation and data handling

5. the National Earthquake Information Service (NEIS)

A national digital seismograph network would consist of broadband, high-dynamic-range, three-component seismographs at a few tens of sites in the United States. It would serve as a stable interface between global seismographic networks and regional networks. It would provide a high-quality long-term data resource required for scientific and engineering purposes, giving uniform national coverage for earthquakes of magnitude 3.5 and greater.

The availability of high-quality, three-component broadband, high-dynamic- range digital data will allow application of sophisticated, but proven, analytical methods to extract new information on earthquake source parameters, and on path properties and geometries that heretofore were not available in the lower-quality data.

At present, elements of a national digital network exist, but they are not integrated. A mix of stations could be specified as selected units from

1. national digital WWSSN
2. elements of regional networks
3. RSTN
4. national SRO/ASRO
5. U.S. Telemetered Seismic Network of 1980, which serves the NEIS early location responsibilities by drawing on selected short- and long-period data generated by regional networks
6. National Tsunami Warning Network

Clearly, coordination and some standardization of selected elements from these networks could constitute a national digital network.

ASSESSMENT OF PROBLEMS

To date there has been no commitment to or funding for the USSS concept. In the past, the seismological community has been slow to recognize the value of a coordinated and integrated national approach to some scientific as well as practical problems. Operators of the more mature regional networks stress that some of their problems could be alleviated by coordination and integration on a national scale. It is likely that costs would be significantly cut with an integrated system. Because of the low priority given to USSS by most of the seismological community, and because the funds recommended for this purpose do not seem to be obtainable in the near future, the federal government has not yet seen fit to endorse the total concept in the form of a commitment by any agency. It is important for the community to perceive that major elements of a national digital network exist in fact, and that evolution of USSS can be controlled in a manner designed to satisfy national needs and priorities.

Many of the present regional networks, however, are products of parochial applied research objectives. There is currently little coordination at a national scale. Instrumentation, data handling functions, data processing, data exchange, and data archiving are thus not standardized. This state of affairs is not conducive to the development of long-term national integration of stations into USSS.

RECOMMENDATIONS

The committee endorses the adoption of the concept of an integrated U.S. Seismograph System.

It is recommended that the Working Group on Seismic Networks to be established by the Committee on Seismology be charged also with guiding the development of the new integrated USSS and a move toward a national digital seismograph network. The nature of the working group is discussed in the introduction to this report. This working group should be the same group that represents the seismological community on the overall problems of seismograph networks, augmented with specialists from time to time as needed for problems specific to a national network. Members and specialists would include network data users, instrument specialists, computer specialists, academic network operators, an operator of an USNRC-funded network, and a USGS network operator. All members should be qualified, experienced seismologists, and, calling upon specialists as needed, they will recommend standards and options in the national network context related to the following topics:

- instrumentation
- network optimization
- data processing and products
- data management and archiving
- data dissemination and centers for regional data

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APPENDIX A

GLOBAL NETWORK DATA

A-1	Map showing distribution of WWSSN stations.
A-2	Map showing distribution of GDSN, IDA, and RSTN stations.
A-3	WWSSN data services.
A-4	Objectives and funding options in <u>Earthquake Prediction and Hazard Mitigation: Options for USGS and NSF Programs</u> (NSF 1976), under the Global Seismology Sub-Element of the Fundamental Earthquake Studies Element.
A-5	Funding history for Global Seismology Branch, USGS. Total funds include, in addition to direct program funds, funding received from other agencies and program elements. FY 1983 numbers are projected.
A-6	Summary of global network options and possible consequences.
A-7	Statement in support of analog WWSSN data.

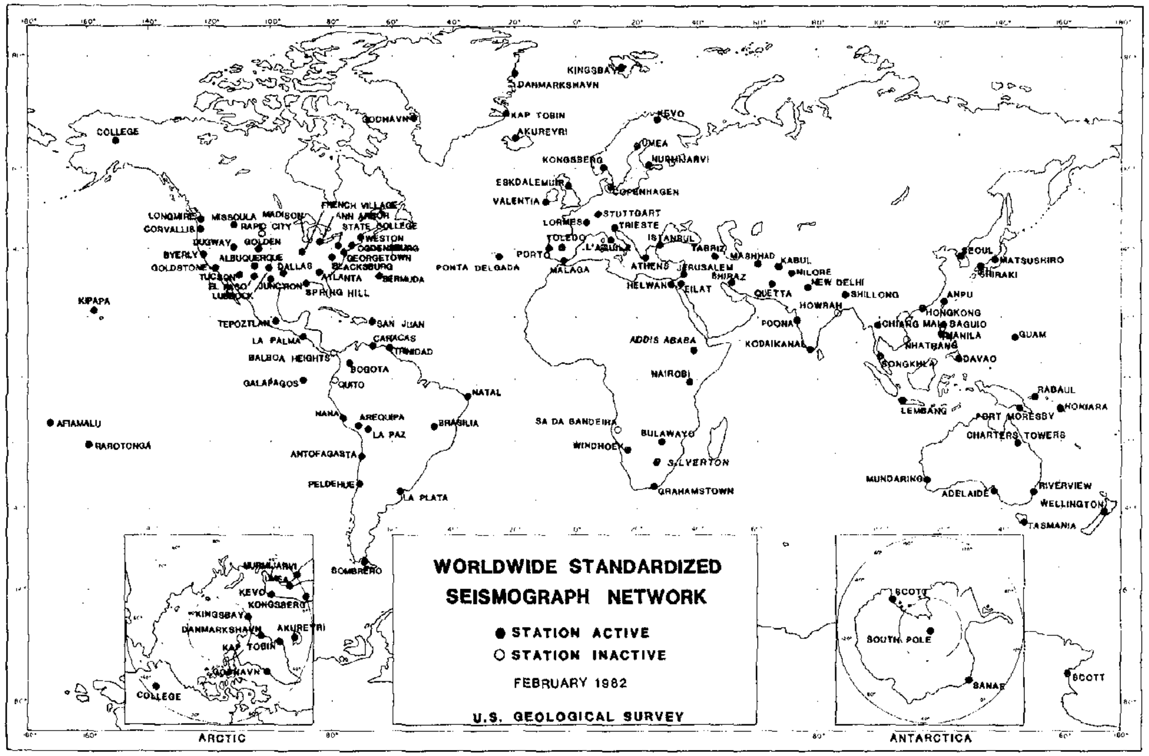

EXHIBIT A-1 Map showing distribution of WWSSN stations.

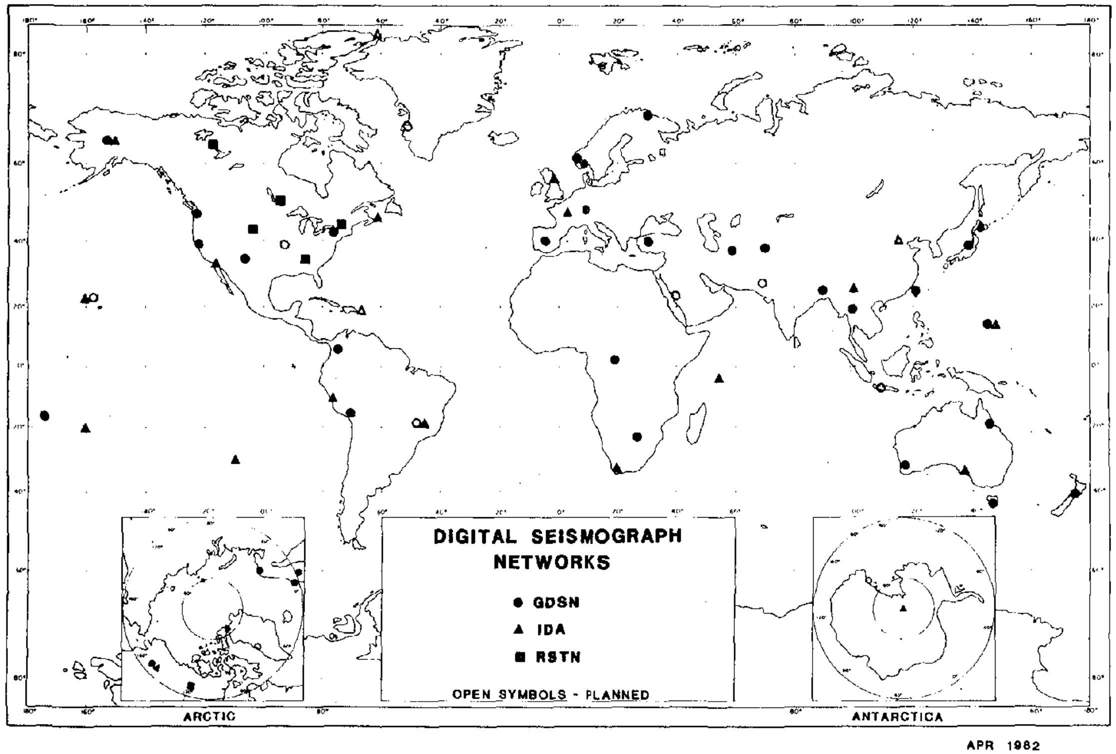

EXHIBIT A-2 Map showing distribution of GDSN, IDA, and RSTN stations.

EXHIBIT A-3

WWSSN data services.

An essential part of the WWSSN from its inception was the microfilming of the original records and the provision of high-quality film copies. Since its beginning in 1961, more than 5 million original records have been copied and 60 million copies supplied to users. Currently, there are several hundred requests per year for seismogram microfilm. The network had an intended size of 125 stations and still operates with about 110 stations. Originally, the seismograms were filmed on specially designed 70-mm panoramic cameras at 8X reduction. In 1978 filming was changed to put 24 images (4 days of normal operation) on a single 105-mm microfiche at 32X reduction. Standing orders of the whole network have been provided to eight institutions (Lamont-Doherty Geophysical Observatory; Institute of Geological Sciences, Edinburgh, U.K.; University of Tokyo; California Institute of Technology; Massachusetts Institute of Technology; USGS/Menlo Park; USGS/Golden; NGSDC/CIRES), and substantial parts of the network have been supplied to five institutions (University of Texas/Galveston; Cornell University; University of Otago (New England); Los Alamos National Laboratory; USGS/Albuquerque).

The network is augmented by copies of the visible records from the HGLP (1), ASRO (4), and SRO (12) networks, from the Canadian network on 35-mm film since 1966, from the People's Republic of China 17-station national network on 70-mm since 1980, and for large-magnitude or seismologically important earthquakes from several hundred additional stations including those of the USSR under the International Data Exchange.

The system is operating primarily with contract labor and with about 8 weeks being required for the cycle from receipt of original records to supplying copies to users. Fifty percent of the network data is generally available for distribution within 8 months after the recording interval. In general the archival film copy is made at NOAA expense with the cost of copy being borne by the user. Present costs to users are $0.80 per fiche, but this will undoubtedly increase as contract costs rise.

EXHIBIT A-4

Objectives and funding options in Earthquake Prediction and Hazard Mitigation: Options for USGS and NSF Programs (NSF, 1976), under the Global Seismology Sub-Element of the Fundamental Earthquake Studies Element.

Global Seismology--Collect and disseminate seismological data from around the world.

1. Operate the World-wide Standardized Seismograph Network (WWSSN) and reestablish a maintenance program for the stations that lapsed several years ago.

2. Operate the data acquisition and processing capability of the National Earthquake Information Service, including use of satellite telecommunications, issuance of new seismicity maps, and routine computation of the parameters of the earthquake mechanism.

3. Upgrade about half of the WWSSN and establish the capability to produce integrated tapes of digital seismic data.

4. Acquire and operate a ten-station array of transportable broadband seismographs for global seismic studies.

5. Operate an integrated digital network consisting of high-gain long-period stations, Seismological Research Observatories, and the upgraded WWSSN stations called for in activity 3, and produce integrated tapes of digital seismic data.

6. Acquire, install, and operate 10 ocean-bottom seismographs.

Present and Proposed Funding Options
Element: 1. Fundamental Earthquake Studies

Option A will allow a stable, minimally sufficient, operation of the WWSSN and operation of the data acquisition and processing capability of the National Earthquake Information Service (NEIS) in FY 1978-1980, a very limited start in upgrading a few of the WWSSN stations in FY 1979, and the incorporation of the

Sub Element	FY 76	FY 77	FY 1978			FY 1979			FY 1980		
	Act.	Req.	A	B	C	A	B	C	A	B	C
a. The Earthquake Process NSF	1.1	1.6	2.3	2.6	3.4	2.6	3.0	3.6	3.0	3.3	3.8
b. The Implications of Plate Tectonics for Earthquake Hazard Reduction NSF	1.5	1.9	2.4	2.7	4.1	2.7	3.0	4.0	3.0	3.3	3.9
c. Global Seismology USGS	1.9	1.7	2.3	2.6	3.2	2.5	3.1	3.6	3.4	3.6	4.0
TOTAL	4.5	5.2	7.0	7.9	10.7	7.8	9.1	11.2	9.4	10.2	11.7

(Amounts are in millions of dollars)

existing high-gain long-period stations and Seismic Research Observatories into an expanded WWSSN in FY 1980.

Option B will allow a partial reestablishment of the maintenance program that lapsed several years ago and the upgrading of about half of the WWSSN stations to produce integrated types of digital seismic data by the end of FY 1980.

Option C allows the acquisition and operation of a 10-station array of broadband seismographs for global seismic studies.

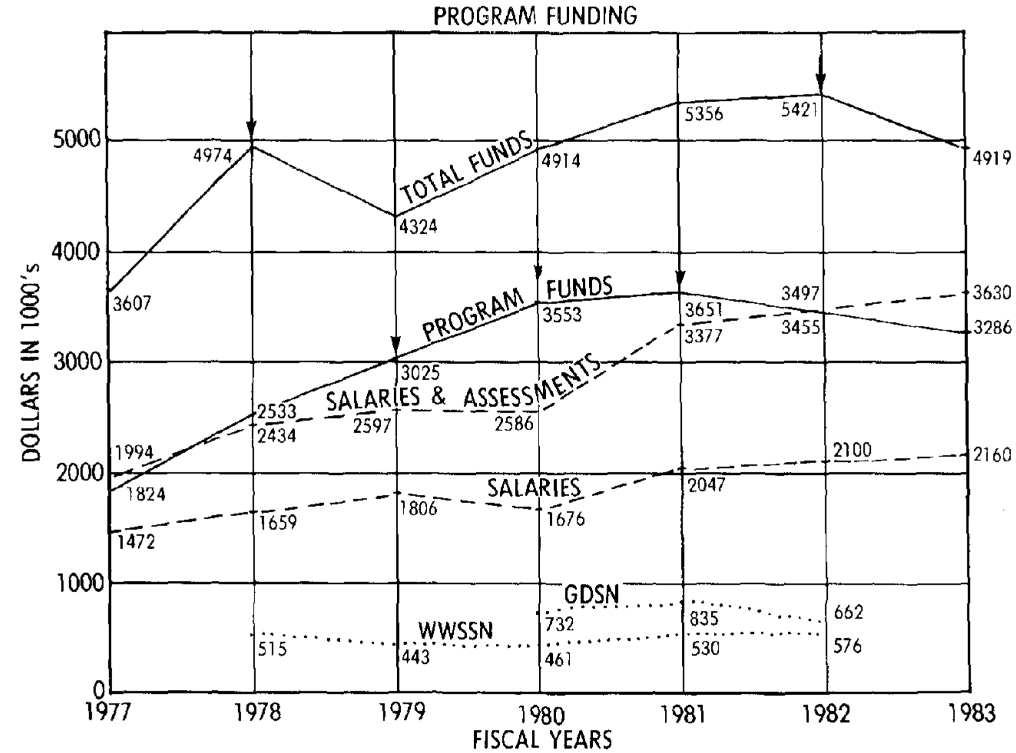

EXHIBIT A-5 Funding history for Global Seismology Branch, USGS. Total funds include, in addition to direct program funds, funding received from other agencies and program elements. FY 1983 numbers are projected.

EXHIBIT A-6

Summary of global network options
and possible consequences.

The following options are those considered by the USGS in its deliberations for the FY 1983 budget, and offered to the Committee on Seismology for its comments and recommendations on behalf of the scientific community. They are an excellent example of the options that have been considered in recent years and that have given rise to this workshop:

1. Terminate all USGS support for the WWSSN. It may be assumed with certainty that the network will cease to function if the USGS withdraws support. Most of the foreign stations are located in developing or under-developed countries that do not have the hard currencies needed to purchase operating supplies even though the annual costs of supplies are small. Even more important, all of the stations, whether they have adequate funding or not, depend upon the USGS Albuquerque Seismological Laboratory as the only source of replacement parts and components, which are no longer manufactured by private industry. Thus a decision to withdraw support would mean the demise of the WWSSN within 1 or 2 years. Of course, the data exchange, which is the purpose of the entire program, would end abruptly.

2. Seek support for the WWSSN from the stations and/or foreign governments. Based on past experience, we are not optimistic that such an appeal would produce results of substance. Many WWSSN stations continue to operate only because of traditional obligations to global seismic data exchange engendered by the network. However, it is doubtful that this goodwill will extend to supporting with their internal funds what in many cases is considered obsolete equipment in comparison with other, more modern stations serving their national needs. In this competition for funds, WWSSN stations are bound to deteriorate and finally terminate operations. Another concern is the apparent incongruity between the considerable funds being expended on the Digital WWSSN upgrade and other new programs and a plea on our part for several thousand dollars in support funds from a host country. Such a plea might also send out unintentional signals that the WWSSN has lost or is losing its importance to the worldwide seismological community.

3. Terminate photographic supplies to all U.S. WWSSN stations. Termination of supplies to 21 U.S. stations would result in an annual saving of about $70,000. Although international obligations will be met, our national needs will not, since many U.S. stations will be forced to terminate operations.

4. Reduce trace spacing from 10 mm to 5 mm on all WWSSN long-period components. The reduction in requirements for photographic paper would result in an annual saving of about $75,000. Present fiche format is arranged to line up all six components for each day in one column for the ease of users. There would be a slight inconvenience to users in that in the new recording pitch long-period data would appear only in the first and third column. The degradation of data will in some instances be unacceptable to users.

5. Replace WWSSN photographic paper recording by rectilinear recording on heat sensitive paper. This change in the WWSSN recording medium would result in an annual saving of about $335,000. Operationally, the change would result in less losses due to developing errors and light intensity problems and in more uniform microfiche images. The total one-time cost for procurement and installation of heated pen assemblies would be about $1,400,000.

6. Eliminate WWSSN short-period horizontal recordings. The reduction in requirements for photographic paper would result in an annual saving of about $100,000. Loss of short-period horizontal data would seriously curtail current studies of the earth's anisotropic properties and of the regional discrimination problem.

7. Terminate all USGS support for the GDSN. A capital investment of more than $10,000,000 would be lost. An opportunity to establish a resource of great potential will be irrevocably lost to seismology for many years in the foreseeable future. Principal advantages of GDSN data are the wide dynamic range, bandwidth, resolution, and the ease and speed with which large amounts of data can be processed. Without these data it will not be possible quickly to test and verify recent and future advances in theoretical seismology by comparing synthetic waveforms and spectra against large volumes of high-quality digital data. The routine use of many digital processing techniques, until recently impeded by the lack of resolution in analog recording, will not be possible without digitally recorded data.

8. Support a Global Seismograph Network (GSN) that combines the GDSN and WWSSN stations. Given this choice, three options are open to the USGS: (a) reduced support for the WWSSN in favor of the digital stations, (b) reduced support of the digital stations in favor of the analog stations, and (c) redirection of funds from other elements of the Earthquake Hazards Reduction Program within the USGS to the support of the global networks.

EXHIBIT A-7

Statement in support of analog WWSSN data.

The WWSSN has been by far the most productive general-purpose network of seismograph stations ever operated. The instruments now consist of moving coil pendulums coupled with recording galvanometers. Free periods are 1 and 0.75 s, respectively, for the short-period instruments and 15 and 100 s for the long-period. However, the cost of photographic paper to record three components of short-period and three components of long-period motion at some 100 stations amounts to about $300,000 annually. This expense can reasonably be questioned since the underlying technology here is about 25 years old. Thus we see pressures for the option of reducing the analog WWSSN system.

Let us examine the underlying WWSSN issues in three parts, the first two being amenable to scientific discussion and the last, more nebulous.

Analog or Digital Recording?

Digital recording will supplant analog. The present advantages of analog have largely to do with merits that can be maintained as the transfer to digital recording is accomplished. Thus digital now offers nothing like film chip distribution nor the archiving that is so easily done with analog. This last point is very serious. We have the example of LASA digital data--of which very little remain. In the year 2000 or beyond, let us imagine that we wish to look back on the previous decades and apply new theories as we study some of the seismic activity preceding a great Alaska earthquake that might have occurred in, say, 1990. The archive will be essential.

We should not underestimate the present advantages of well-written paper records. As one looks over the sheet, there is an enormous amount of detail in a compressed format contributing to a sense of where one is, with respect to noise levels, across a quite wide frequency band (for WWSSN long periods) and a substantial dynamic range. The trained eye can absorb this information rapidly. Although accepting the merits of properly written digital equivalents (absence of overlapping traces, lack of human error in digitizing, suitability for data analysis), there is a considerable loss in going from analog to digital facsimilies of LP WWSSN at one sample per second.

Global Coverage

There are now about 100 more stations in the WWSSN than in the GDSN. Many seismologists claim that without that extent of global coverage, we would go back into the dark ages of seismology. This point of view applies not only to those studying tectonics and regional problems, but also to those studying the upper 700 km of the mantle. The many structures proposed differ from one another because of the earth's lateral variability. The problems of inverting seismic data from too few stations have a history as long as that of the science itself.

For many scientific purposes, the main pressure should be on expanding coverage rather than improving technology. Thus the many special problems associated with Alaska, and comparisons with the coverage by standard stations in Canada (about 34), indicate about six to eight more Alaskan stations are necessary. Work is required to improve South American stations. They sometimes do not submit data for days on which South American earthquakes occur. Of course, island stations in the world's oceans are critical.

Work Habits of Analog Users, As Compared to Those of Digital Users

This is the nonscientific part of the issue, but it must be addressed because opinions are strongly held.

In many cases, seismology is not applied as a "stand alone" science. Rather, it has links to materials science, structural geology, gravity, heat flow, geomagnetism, and remote sensing. Those scientists who wish to proceed on a broad front with data from various disciplines will typically not now make what they perceive to be a heavy investment in digital hardware (tape drives, plotting devices, etc.), nor take the time to master a digital facility if offered. This remark obviously does not apply to those close to discrimination/verification problems, or to those in exploration/prospecting. In those fields, a digital revolution has already been accomplished and is appropriate.

For the broader view of seismology, consider a couple of examples. A recent review of geophysical and geologic evidence strongly suggests the Makran region of Pakistan and Iran is now an active subduction zone and probably has been during most of the Cenozoic. Oceanic portions of the Arabian plate currently subduct northward toward Eurasia with a relative motion of about 5 cm/year. The Makran region consists of a nearly complete trench-arc system; however, some of its tectonic features are somewhat atypical. For example, an abundant supply of sediments seems to lead to a shallow dip for the subducted Arabian plate, and it does not permit a bathymetric trench to develop; the accretionary prism is very wide, and a large part of it is subaerially exposed rather than being submarine; only moderate seismicity occurs in the shallow-dipping thrust zone; at subcrustal depths the dipping seismic zone has a weak and sporadic expression to depths of only 80 km and is not documented at larger depths; the volcanic arc is poorly developed with large spacing (about 100 km) between its major Quaternary volcanic centers; the trench-volcano gap measures 500 $\pm$ 100 km, more than twice the width of a typical trench-volcano gap.

Despite these peculiarities, geologic, geophysical, and plate tectonic data suggest an active plate boundary with ongoing subduction beneath the Makran region. It is a rapidly accreting continental margin, large portions of which are still underlain by a mobile oceanic basement.

This work in Asian tectonics, which made major uses of WWSSN data, would not in practice have reached the same insights if only the sparser GDSN data had been available. To say whether that is important or not is a value judgment.

Consider another example: In the proceedings volume of the last Ewing Symposium--Earthquake Prediction, An International Review (American Geophysical Union, 1981), edited by David W. Simpson and Paul G. Richards--about one quarter of the papers used data coming in large part from the WWSSN. Furthermore, except in a couple of cases, the future research anticipated by these papers would still use such a data base.

It is healthy that some seismologists are driven to diversity in the direction of other earth sciences, and some to diversity in the direction of signal-processing and information theory. The present merits of film-chip distribution are recognized by all seismologists, and something like this widespread distribution system for visible records should be maintained even with a digital data base. This is stated in Global Earthquake Monitoring (NRC, 1977a, pages 31, 42) and in the report of the Panel on Data Problems in Seismology (NRC, in preparation).

APPENDIX B

REGIONAL NETWORKS: QUESTIONNAIRES, RESPONDENTS, SUMMARY

DATA BASE

In order to conduct informed discussion on the problems facing regional network seismology in the United States, a reasonably complete data base was required. Our approach was to find as many networks as possible, through a concentrated investigative effort, and to survey the operators for factual data on their networks and for their opinions on a number of questions.

Fifty-three more-or-less separate networks were found, distributed throughout the United States, including Hawaii and Alaska, along with four relatively permanent networks operated in foreign countries by U.S. investigators. Two of the networks included were recently shut down, and others soon may be, due to funding limitations. Network size ranged from 2 to 315 stations, with about half of them in the 10 to 40 station-size range. Exhibit B-1 of this appendix gives the listing of the networks found, along with the approximate number of stations (some uncertainty creeps into this number due to joint operations, network overlaps, etc.), and an indication of those networks for which we received a questionnaire response. The 47 operating U.S. regional networks involve 1631 separate stations, according to our figures.

The questionnaire used is reproduced as Exhibit B-2. It was formulated with the intent that it be relatively easy to complete (only 2 to 3 weeks were available before the workshop), and that it allow alternative ways of providing the basic network data and operators' opinions. Forty-five responses, in varying detail, were received. We view this near-unanimous response as a unified recognition of a serious need to address the problems of regional networks. The following section summarizes the data and opinions supplied by the 45 respondents.

QUESTIONNAIRE RESPONSE SUMMARY

Sections I, V

All but one respondent favored holding the workshop and thought that useful results were possible. Concern was expressed over the lack of wider representation from operators and over the overwhelming complexity of the problems.

"Crucial questions" posed by respondents covered such matters as rising telemetry costs, the mixing of operational and research costs, need for stable policy and funding, precariousness of the northeast United States network support, wide variability of data quality, instrumentation improvements, coordination of hardware and software development, the unique role of Alaska in U.S. seismology, future of global and national networks, an assessment of the value of current network practices, and the growing usage of seismologists as technicians.

Section II

If we exclude the Washington and Caltech cooperative USGS networks (WC) and the 10 other USGS networks (G10), the remaining 33 regional networks (33) are operated by the organizations with the following average number of personnel and total budgets devoted to seismological studies:

Senior research personnel	3.9
Graduate students	5.6
Technical staff	3.0
Total annual seismology budget	$236,000

The $60,000 average total yearly support per senior research scientist holds for all non-USGS institutions.

Section III

Here again we must separate the population according to the WC, G10, and 33 groupings, with the following results:

	WC	G10	33
Annual data acquisition plus processing costs per station	$4,000	$5,000	$6,000
Ratio of acquisition costs to processing costs	1.4	1.2	1.0

- All but three networks utilize telemetry.
- Eleven networks operate on-line to dedicated computer systems.
- For the (33) networks, operators estimate that an average 35 percent of their institutions' seismological programs (in terms of both cost and scientific output) are supported by the network.
- Most of the networks are felt to be of indefinite lifetime, although several of the special-purpose networks were initially installed with definite 3- to 7-year expected durations.
- The question on nonpaying users brought a wide response, with almost all networks involved routinely in providing data in some form to a variety of individual, industrial, and governmental users. Exhibit B-3 illustrates the diversity of users.

Section IV

A 60 percent majority opposed the idea of reducing their network size for fewer higher-quality stations.

The national digital network was favored by 33 and opposed by 5 respondents, with a lack of strong feeling either way.

Questions 23, 24, and 25 revealed a division of opinion between the G10 and 33 populations:

	G10		33	
	Yes	No	Yes	No
Instrumentation adequate?	5	4	10	16
Need to standardize?	4	5	19	6
Separate operations and research funding?	2	7	19	5

A 70 percent majority felt that the present mix of funding agencies is satisfactory. "Major problems facing network operations" were perceived as follows:

No. Responses	Problems
18	Funding, in general, at stable and continuing level
5	Vagaries of agency policy toward regional networks
5	Rising telemetry costs
4	Funding to upgrade equipment
1	Generally poor data quality
1	How to cut operational costs

EXHIBIT B-1

Compilation of regional networks surveyed for workshop.

U.S. Regional Seismic Networks

Questionnaire Returned	Northeastern Seismographic Networks (and operators)	Approximate No. of Stations
Yes	1. New England Network--Boston College	38
Yes	2. New York Network--LDGO	38
No	3. MIT Network--MIT	9
Yes	4. Penn. State Network--Penn. State	16
No	5. Delaware Net--Delaware Geological Survey	3
Yes	6. SUNY at Stony Brook	2
	Subtotal	106
	Southeastern Seismographic Networks	
Yes	7. Virginia Network--VPI	31
Yes	8. Southern Appalachian Regional Network--Tennessee Earthquake Information Center (Memphis State)	18
Yes	9. South Carolina Seismic Program--University of South Carolina and USGS Charleston Net	38
Yes	10. Central Georgia Net (Wallace Dam)--Georgia Tech.	5
Yes	11. Northern Alabama Seismic Network--Alabama Geological Survey and Georgia Tech.	12
Yes	12. Georgia Tech. Networks--Georgia Tech.	15
	Subtotal	119
	Central United States Networks	
Yes	13. New Madrid Network--St. Louis University	70
Yes	14. Kansas Network--Kansas Geological Survey	19
No	15. Oklahoma Seismographic Network--Oklahoma Geological Survey	10
Yes	16. Ohio, Indiana, Michigan Network--University of Michigan	14
Yes	17. Central Minnesota Seismic Array--University of Minnesota	6
Yes	18. Nebraska Nemaha Ridge Seismic Net--Nebraska Geological Survey	4
Yes	19. Memphis Area Regional Seismographic Network--Tennessee Earthquake Information Center (Memphis State)	13
	Subtotal	136
	Intermountain Seismographic Networks	
No	20. Montana Network--Montana Bureau of Mines	7
Yes	Yellowstone Network--USGS (discontinued October 1981)	
No	21. Southeastern Idaho Network--DOE and Bureau of Reclamation	8
Yes	22. Southern Intermountain Net--University of Utah	81

Questionnaire Returned	Intermountain Seismographic Networks	Approximate No. of Stations
Yes	23. Northern New Mexico Net--Los Alamos	24
Yes	24. West Texas Network--University of Texas, El Paso	6
Yes	Albuquerque Network--USGS (discontinued October 1981)	
Yes	25. Socorro Network--USGS	12
Yes	26. San Juan Basin Network--USGS	5
Yes	27. Southern Nevada Network--USGS	53
Yes	28. Nevada Network--University of Nevada, Reno	40
No	29. Southeast Utah Network--Woodward-Clyde	23
	Subtotal	259
	Alaskan Networks	
Yes	30. Southern Alaska Network--USGS	53
Yes	31. Shumagin Islands--Lamont-Doherty Geological Observatory	35
Yes	32. Adak Network--CIRES	15
Yes	33. Unilaska, Dutch Harbor Array--Lamont Doherty Geological Observatory (one half will close summer 1982)	7
Yes	34. Central Alaska Network--University of Alaska	12
Yes	35. Western Alaska Network (Seward Peninsula) (will close summer 1982)	18
Yes	36. Kodiak, Cook Inlet Network (will close summer 1982)	33
	Subtotal	173
	West Coast Networks	
Yes	37. Washington Network--University of Washington	132
Yes	38. Oregon Network--State University of Oregon	6
Yes	39. Cascade Network--USGS	48
Yes	40. Berkeley Network--University of California, Berkeley	18
Yes	41. Central and Northern California Network--USGS	315
Yes	42. Southern California Network--Caltech	34) com-) bined
No	43. Southern California Network--USGS	156) netwo
Yes	44. Los Angeles Basin Network--University of Southern California	43
Yes	45. ANZA Network--University of California, San Diego	17
No	46. California Department of Water Resources	20
Yes	47. Hawaiian Volcano Observatory Network--USGS	49
	Subtotal	838
	Selected Other Networks	
Yes	Caribbean Network--Lamont-Doherty Geological Observatory	25
Yes	Resnor Network--University of California, San Diego	14
Yes	Nurek Reservation, USSR--LDGO	6
Yes	Toktogal Reservation, USSR--LDGO	6

45 Responses

East Coast	225	stations
Central United States	136	
Intermountain	259	
Alaska	173	
West Coast	838	
Total	1631	stations in United States

EXHIBIT B-2

Operator's questionnaire: local/regional seismographic network.

I. The Workshop:

1. Do you favor its being held? (Y) (N)
   If no, why?

2. Are you comfortable with the proposed workshop agenda and plan? (Y) (N)
   If not, suggest modifications:

II. Your Institution:

3. Personnel involved in all seismological studies:

	Number
a. Senior Research Scientists:	______
b. Graduate Students:	______
c. Technical Staff:	______

4. Approximate total annual budget: $ ______

III. Your Network: (Include station map and complete this section for each clearly separate network.)

5. Number of Stations and Types:

a. SP (Z only)	______
b. SP (3-component)	______
c. Broadband/LP	______
d. (Other) ______________	______
e. Total No. Data Channels	______

6. Data Transmission:

a. No. stations telemetered	______
b. Approximate total line miles	______
c. Percent radio telemetered	______
d. No. stations recorded locally	______
e. Percent also telemetered	______

7. Data Acquisition/Recording:

	Sta.	Cha
a. No. stations & channels on-line to computer	______	______
b. No. stations & channels recorded analog mag tape	______	______
c. No. stations & channels recorded digital mag tape	______	______
d. No. stations & channels event recorded only	______	______
e. No. stations & channels analog recorded only	______	______

8. Data Acquisition Costs (yearly):

	$	Full-time staf
a. Telemetry costs	______	______
b. Out-station maintenance	______	______
c. Central station maintenance	______	______

9. Data Processing and Analysis Costs (yearly):

a. Dedicated full-time equivalent staff	______
b. Personnel costs	______
c. Supplies and expenses costs	______

10. Purpose of network as originally installed:

11. Is purpose still same? (Y) (N)
    If no, how changed?

12. Funding sources/annual support:

13. Was there initially a general agreement on the expected duration of operation? (Y) (N)

14. If yes on 13:

    a. How many years? ________

    b. Basis for this lifetime:

15. If no on 13:

    a. Do you have a proposed duration to accomplish present purpose?

    b. If so, what?

    c. What fraction of the net, if any, should remain indefinitely?

    d. Explain b. and/or c.:

16. Dissemination of Results:

    a. Do you generate a regular bulletin? (Y) (N)

    b. Do you generate seismicity maps? (Y) (N)
       (from network--not historical)
       If yes, send recent sample.

    c. Have research papers been published in open literature using network? (Y) (N)
       If yes, send list of papers 1979 to present.

    d. What is your opinion as to the major scientific or engineering result(s) of your network operation and what do you hope to learn from its continued operation? (Use additional sheets as necessary.)

17. Are there other (non-paying) users or agencies relying on your network data? (Y) (N)

    If yes, describe their usage and try to estimate the cost of this service.

18. What percentage of your institution's seismology program (exclude teaching) does this network support?

    a. In terms of total cost: ____________

    b. In terms of scientific output: ____________

IV. Some of your opinions:

19. Can you see any merit in reducing your network size for fewer higher-quality stations? (Y) (N)
    Explain (Y) or (N):

20. A national digital network:

    a. Do you see value in it? (Y) (N)
       Comments:

    b. Would you assign your best upgraded station(s) to such a network? (Y) (N)
       Explain no:

21. What do you see as the major problem facing your network operation?

22. Your ideas on a practical solution to this problem:

23. In general, do you think your instrumentation is adequate? (Y) (N)
    If no, explain:

24. Do you see any need for an effort to standardize network instrumentation throughout the country? Explain.

25. Do you feel network operational and analysis costs should be funded separately from basic research? (Y) (N) Why?

26. Do you think that there are too many (or too few) agencies responsible for local/regional network operations and/or national and global networks?

27. Where do you think policy-making responsibility should rest for setting directions and priorities for new developments in network seismology?

V. The Workshop (again):

28. Do you think it can produce a useful analysis and recommendations?
(Y) (N)
If no, why?

29. Finally, please list your 2 or 3 "crucial questions" you would like the committee to be certain to address:

a.

b.

c.

Many thanks for your time.

EXHIBIT B-3

Example users of regional network data.

Earthquake data, as recorded by a regional seismic network, are usually made available to the public in the form of network bulletins, catalogs, and maps. These data, together with the original seismograms, are used, usually by the collecting institution, as the basis for fundamental research on the nature and distribution of regional earthquakes. Results of such research are published in scientific journals and reported at scientific meetings. This research is usually of a quite directed nature, if funded by the agency or institution sponsoring the network and is more fundamental if funded by the National Science Foundation or similar agencies.

It is not often realized the extent to which some of these data are used by other than the sponsoring agency and the scientists of the collecting institution. It is not possible to list all of the users of all of the network data. It is instructive, though, to discuss a few specific cases where such information is reported.

As a first case let us consider the well-known 190-station Caltech network (as currently augmented by a number of USGS stations). Network operators routinely cooperate with each other and with the National Earthquake Information Service (NEIS). In the case of the combined Southern California Network, data from the following networks are used in routine locations:

USGS Southern California
USGS Nevada Network (selected stations)
USGS Walker Pass Network
Caltech Network (telemetered stations only)
California Department of Water Resources
University of California, Berkeley
University of Southern California
University of Nevada

Also, telemetered signals are sent out from the Caltech net to the following groups:

California Department of Water Resources (and then to NEIS, Golden)
University of California, San Diego
University of California, Riverside

California State University, Fullerton
Naval Weapons Center, China Lake
Pasadena City College

Groups on Caltech's routine emergency call list (called 34 times last year) include:

California Office of Emergency Services
California Department of Water Resources
California Division of Mines and Geology
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers
U.S. Geological Survey, Seismic Engineering Branch
Federal Emergency Management Agency
Federal Power Commission
National Earthquake Information Service (USGS)
American Red Cross
Los Angeles Department of Water and Power
Pacific Tsunami Warning Network
Los Angeles County Emergency Information Bureau

Companies and agencies that financially support the Seismological Laboratory as members of the Caltech Earthquake Research Affiliates, because of their interest in southern California earthquake problems, include:

Atchison, Topeka, and Santa Fe Railroad
C. F. Braun and Company
Dames and Moore, Inc.
Factory Mutual Engineering
ERTEC, Inc.
International Business Machines, Inc.
Kinemetrics, Inc.
Exxon
Los Angeles Department of Water and Power
Lockheed California Company
Metropolitan Water District of Southern California
Pacific Telephone and Telegraph Company
San Diego Gas and Electric Company
Southern California Edison Company
Southern California Gas Company
Southern Pacific Company
Standard Oil Company of California
Union Pacific Railroad Company
Union Oil Company of California
Woodward-Clyde Consultants
Bank of America

Bulletins are sent monthly to 250 interested parties--particularly to engineering and geotechnical consulting firms.

The 81-station Utah network, in the Intermountain Region, lists their chief, nonpaying users as follows:

Utah Geological and Mineral Survey (for geological hazard studies)
Mining, utilities, construction, petroleum exploration, and miscellaneous engineering consulting companies (for specific site-evaluation studies)
State and county government offices (for planning and emergency services)
USGS/NEIS (for regional earthquake recording)
U.S. Bureau of Reclamation (dam safety)
U.S. Forest Service (geological hazard studies)
U.S. Soil Conservation Service (dam safety)
U.S. Army (geological hazards)

Lamont-Doherty Geological Observatory, in the East, reports that their network operators spend approximately 10 percent of their time in providing data to engineers and private consultants who require information about hazards, plus the news media and private citizens who regularly contact them for information on earthquake hazards with the desire to be educated about earthquakes in general.

Virginia Polytechnic Institute and State University lists:

Virginia State Office of Emergency and Energy Services (for planning)
Virginia State Fire Marshal's Office
The Virginia Chamber of Commerce (for industrial siting studies)

These few examples demonstrate that the users of regional seismic data are many and varied, including other networks and the NEIS; a plethora of federal, state, and local agencies for planning and emergency services; major utility companies; engineering and geotechnical consulting firms; petroleum exploration companies; and many other public and private groups interested in seismicity and earthquake hazards.

APPENDIX C

SUMMARY AND MAJOR RECOMMENDATIONS OF U.S. EARTHQUAKE OBSERVATORIES: RECOMMENDATIONS FOR A NEW NATIONAL NETWORK

The report on U.S. Earthquake Observatories is the first attempt by the seismological community to rationalize and optimize the distribution of earthquake observatories across the United States. The main aim is to increase significantly our knowledge of earthquakes and the earth's dynamics by providing access to scientifically more valuable data. Other objectives are to provide a more efficient and cost-effective system of recording and distributing earthquake data and to make as uniform as possible the recording of earthquakes in all states.

Many problems of major national importance related to earthquakes remain to be solved. Earthquake prediction and the amelioration of earthquake hazards, for example, require uniform, continuous, and standardized earthquake records over the entire country using modern computer-coupled instrumentation. We cannot anticipate all the scientific gains that will accrue from sharply improving the national capability to observe, measure, and study earthquakes, but we can be reasonably sure of many successes. Among the research goals are the quantitative study of sources of earthquakes above magnitude 3.0 up to the greatest earthquakes in the entire United States, a capability never before possible; more reliable understanding and prediction of strong ground shaking; the precise definition of fine structure in the earth's crust and deep interior using high-resolution techniques; and the close mapping of regional tectonics, related to geological hazards, and location of natural resources. In particular, there is a need to monitor and analyze quickly short-term stress variations in active fault zones for earthquake prediction purposes, a high national priority.

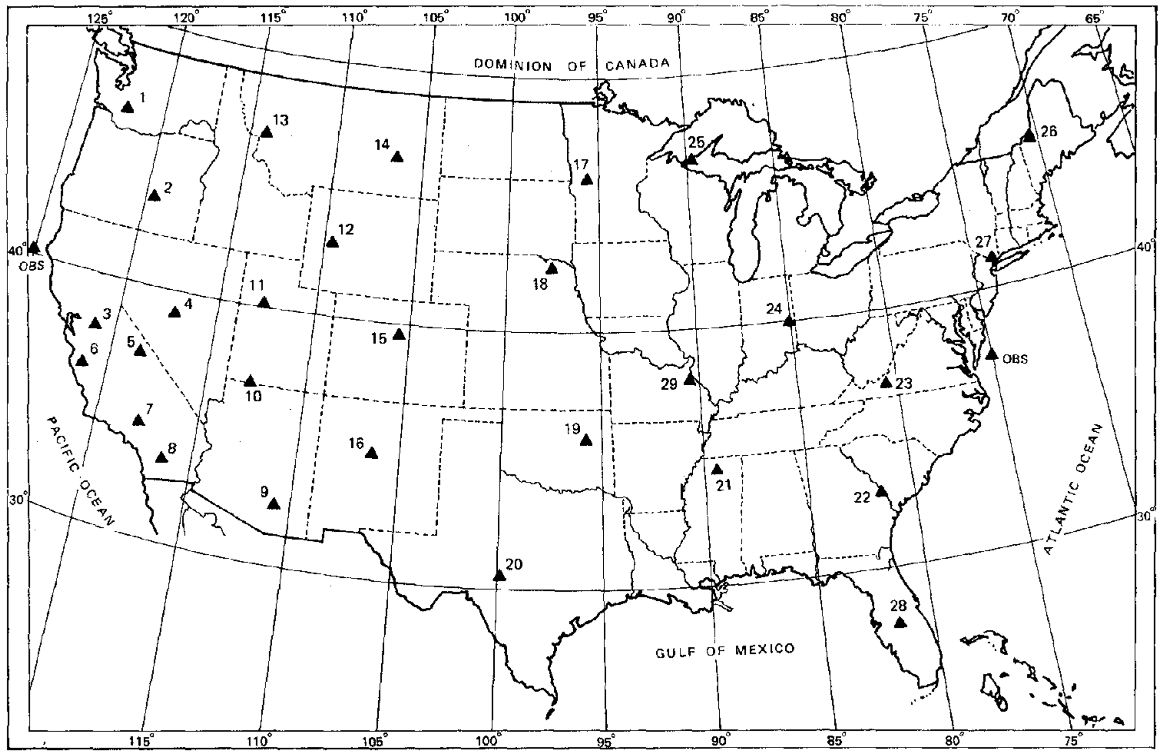

EXHIBIT C-1 Proposed locations of 29 continental and 2 ocean-bottom observatories for the National Digital Seismograph Network (NDSM).

Two recent developments make the present an appropriate time to move ahead by redesigning and consolidating the uncoordinated mixture of local, regional, and national earthquake observatories, many of which are obsolescent. The first development is the new technology based on digital sampling of signals. The second is the decisive advance in theoretical seismology, including powerful computational ability, that has created a need for high-quality observations of seismic waves, with wide dynamic ranges in both frequency and amplitude.

For the attainment of research and applied goals, data analysis, archiving, and retrieval capabilities in the United States need streamlining, partly centralizing, so that digital tapes, seismograms, and the derived seismicity data from all stations are available in a short time to all users.

In order to bring together these components, the central recommendation of the Panel is that the guiding concept be established of a rationalized and integrated seismograph system consisting of regional seismograph networks run for crucial regional research and monitoring purposes in tandem with a carefully designed, but sparser, nationwide network of technologically advanced observatories. Such a national system must be thought of not only in terms of instrumentation but equally in terms of data storage, computer processing, and record availability. Exhibit C-1 shows the suggested locations of seismograph stations for the proposed National Digital Seismograph Network (NDSN).

In order to take advantage of recent technological and theoretical advances, the concept of an integrated United States Seismograph System (USSS) should be adopted in the United States so that enhanced information on earthquake sources, seismic hazards, ground motions, and earth structure is available.

APPENDIX D

GLOSSARY

ANZA	Local seismicity array located near Anza, California
ASL	Albuquerque Seismological Laboratory
ASRO	Abbreviated Seismic Research Observatory
CIRES	Cooperative Institute for Research in Environmental Sciences
CSS	Center for Seismic Studies
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	Department of Energy
DWWSSN	Digital World-Wide Standardized Seismograph Network
GDSN	Global Digital Seismograph Network
GSN	Global Seismograph Network
HGLP	High-Gain Long-Period
IDA	International Deployment of Accelerometers
LASA	Large Aperture Seismic Array
LDGO	Lamont-Doherty Geological Observatory
MIT	Massachusetts Institute of Technology
NDSN	National Digital Seismograph Network
NEHRP	National Earthquake Hazards Reduction Program
NEIS	National Earthquake Information Service
NGDC	National Geophysical Data Center
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSF	National Science Foundation
RSTN	Regional Seismic Test Network
SRO	Seismic Research Observatories
SUNY	State University of New York
USCGS	U.S. Coast and Geodetic Survey
USGS	U.S. Geological Survey
USNRC	U.S. Nuclear Regulatory Commission
USSS	U.S. Seismograph System
VPI	Virginia Polytechnic Institute and State University
WWSSN	World-Wide Standardized Seismograph Network