EARTHQUAKE PREDICTION RESPONSE AND OPTIONS FOR PUBLIC POLICY

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PREFACE

The benefits promised by long or short-term earthquake prediction technology are most likely to accrue only if careful efforts are made by scientists and public and private decision makers to develop and implement the methods and policies needed to prepare society for response to possible earthquake predictions. This work has been written to assist in that effort, and to provide some indications of how people, organizations and society will respond to scientifically credible earthquake predictions. It is our intention to review the range of possible decisions and behavior elicited by an earthquake prediction, to examine the causes for those decisions and behavior, and to discuss options for changes in policy which promise to maximize the benefits of prediction while minimizing its potential social and economic costs.

In the first chapter we review briefly the history and status of earthquake prediction, global and national earthquake vulnerability, the range of adjustments to the earthquake hazard, the social benefits and possible negative impacts (costs) of prediction, and some general arenas of concern for public policy. Chapter II is a discussion of some social responses to a few actual earthquake predictions and a hypothetical prediction scenario. Chapter III is a review of the problems of method we faced and which accompany social science research into questions about future human behavior. The chapter also documents the different kinds of data and studies on which this work and its conclusions are based. In Chapter IV our findings are presented; earthquake prediction and warning are cast in a model similar to other natural hazard warning systems, and an earthquake prediction-warning system is divided into three constituent elements: (1) giving information, (2) interpreting information, and (3) responding to information. In the chapter we present conclusions about people and organized social collectives with reference to each of the three aforementioned elements of an earthquake prediction-warning system. Chapter V, based on the conclusions in Chapter IV, suggests some issues and options for public and private policy and action.

This work gives persons in public and private positions some tentative answers to questions about social response to earthquake prediction, and, on that basis, proposes some possible and desirable changes in policy. We write this report for people who are able to effect change now and do things that will enhance the future use of earthquake prediction technology. Our audience includes local, regional, and especially state and federal policy and decision makers. Our contributions lie in identifying the range of decisions that a variety of people and public and private decision makers will be faced with during an earthquake prediction.

To some, this work may appear more technical than is necessary to get our point across. To others, including academics and scientists, this work will appear less technical than typical research accounts. We hope that this mid-ground will make this work useful to both scientists and agents of change.

The Authors
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CHAPTER I

INTRODUCTION

Earthquake Prediction and Prediction Research

History and Status of Earthquake Prediction

In 1971, at an international scientific meeting in Moscow, Soviet scientists announced that they had learned to recognize some signs they believed were associated with impending earthquakes. This was the first widespread public knowledge of Soviet prediction research which had been initiated in the mid-1960's. Concurrently, prediction research was being conducted by the Japanese; in the late 1960's prediction efforts first received attention in the United States, and the Chinese Program began to be expanded.

The Soviet scientists indicated that the most important sign of an impending earthquake was a change in the velocity of vibrations that pass through the crust of the earth as a result of disturbances such as other earthquakes, underground nuclear rests, or mining blasts. Earth scientists have long known that vibrations spread outward in two different types of seismic waves. The P wave travels at about 3 1/2 miles a second; it is a longitudinal wave that causes rock particles to expand and contract. The S wave travels at about 2 miles a second near the surface; it causes the earth to move in right angles to the direction of the wave. Because P waves travel faster than S waves, they reach seismographs first. The Russian scientists found that the differences in the arrival times of P and S waves began to decrease markedly for days, weeks, and in some cases, months before an earthquake. Then, shortly before the earthquake strikes, the wave velocities return to normal. The Russians also learned that the longer the period of abnormal wave velocity before an earthquake, the larger the eventual earthquake.

The various changes believed to precede an earthquake are in part explained by dilatancy theory. This theory postulates that stress causes small cracks to appear in rock prior to an earthquake. This accounts for the change in the ratio of seismic waves already described. Dilatancy may also explain other precursors to earthquakes. As cracks open in rock, the electrical resistance of rocks changes, sometimes rising and sometimes falling. The cracks also increase its surface area of rock exposed to water; the water thus comes in contact with more radioactive material and absorbs more radon (a radioactive gas which sometimes has been observed to increase in well water prior to earthquakes). In addition, because the cracking of the rock increases its volume, dilatancy may account for the crustal uplift and tilting that precedes some earthquakes (1964 Niigata earthquake in Japan was preceded by a two-inch rise in the ground).

There is no doubt that some earthquakes have been preceded by changes in observable geophysical quantities; that some earthquakes will be predictable on the basis of precursory anomalous changes seems likely. It is not known, however, if all earthquakes, or even all crustal earthquakes, exhibit premonitory behavior, or if the occurrence of certain precursors is a function of the mode of faulting (strike-slip vs. dip-slip), the tectonic setting (e.g., plate margins vs. intraplate settings), or some other circumstances. For example, the Tangshan earthquake of 1976 in China was not predicted because relatively few precursors were noted. However, the Haicheng earthquake of 1975 and the Sungpan-Pingwa earthquakes of 1976 were preceded by sufficient numbers of precursors for a prediction.

At present, scientists seek to predict three parameters of an earthquake event: time, place, and magnitude. Earthquake prediction also includes some measure or estimate of the confidence the predictor associates with the specification of each of these parameters. Estimation of potential damages is a separate, but important issue.

The places of occurrence of future earthquakes are indicated first by past seismicity, both historic and prehistoric, and by the location of precursory anomalies if they are detected. Seismic gaps along tectonic plate boundaries may indicate an increased likelihood of a future event and provide sites for increased monitoring for anomalous data. The suggestion that hypocenters migrate merits further study. Migration of events was the first clue used by the Chinese in predicting the Haicheng earthquakes. Less is known in regard to intraplate earthquakes, for example, those in eastern North America. Seismologists and geologists do not understand fully why these earthquakes occur, and scientists are seeking to develop better models of these events using tectonic information gained from geophysical and geological investigations. In the vicinity of the New Madrid earthquakes of 1811-12, geologic records show that two previous great earthquakes had occurred within the past 2000 years.

Two clues to the magnitude of an impending earthquake are the size of the area within which anomalous behavior occurs, and the time duration of the anomaly. The direct relation of anomalous area to magnitude is best supported for geodetic data measuring changes in ground elevation, such as is available in Japan. The relationship between anomaly duration and magnitude has been observed for many kinds of precursors.

With regard to prediction of the time of occurrence, the evidence indicates that precursors fall into two populations. One group is characterized by an anomaly duration that scales with magnitude. The other, apparently accompanying only moderate to large eartuqhakes--magnitude 5 and greater--begins very shortly before the event, the duration not dependent on the magnitude. These short-term precursors have generated considerable excitement among scientists (Rikitake, 1976), as they may offer a promising means of detecting large events. Countries such as Japan are now placing great emphasis on research aimed at short-term predictions. Examples of short-term precursors include changes in the magnetic field of the earth, surface changes in the water level of wells, and the supposed altered behavior of some animals.

World Experience with Predictions

Several destructive earthquakes have been usefully predicted in China: the Haicheng earthquake, Liaoning Province, February 4, 1975; a pair of earthquakes 97 minutes apart, magnitude 6.9, near the China-Burma border, May 29, 1976; and a three-event cluster, magnitudes 7.2, 6.7, and 7.2, on August 16, 22 and 23, 1976, at Sungpan-Pingwu, Szechuan Province. All reports, from Chinese and foreign sources, confirm that the Haicheng and Sungpan-Pingwu events were both predicted and followed by effective actions to reduce property losses and injuries.

The prediction of the Haicheng event was based on analyses of long-term seismicity, geodetic observations, changes in radon concentration in well water and water levels, and variations in rates of microearthquake occurrences just before the main shock. A false alarm in December of 1976 apparently caused some discomfort to residents who evacuated their homes in cold weather, but the campaign of mass education on the principles of earthquake prediction, and the involvement of large numbers of amateurs in the observation program, obviously succeeded in preparing the population for such errors. Prediction of the Sungpan-Pingwu earthquakes was based on geophysical data as well as on "macroscopic" anomalies (fire balls, abnormal animal behavior, and turbidity in well water). There was no increase in microseismicity. Successful predictions of damaging earthquakes in China and the USSR are presented in Table I-1.

In the United States, small events have been currently predicted in New York (Stolz, Sykes and Aggarwall, 1973), and in South Carolina

TABLE I-1

SUCCESSFUL PREDICTIONS OF POTENTIALLY DESTRUCTIVE EARTHQUAKES

Place	Date	Magnitude
China		
Haicheng	3 February 1975	7.3
Sungpan-Pingwu	16 August 1976 22 August 1976 23 August 1976	7.2 6.9 7.2
Lungliu	25 May 1976	7.6
Yen Yuan	7 November 1976	6.8
USSR		
Dushanbe	5 November 1976	5.2
Border region Iran-USSR	16 September 1978	7.7
Pamir	1 November 1978	7

(UNESCO, 1979)

(Stevenson, Talwani and Amick, 1976), both on the basis of velocity anomalies. The United States Geological Survey (USGS) has detected clear tilt anomalies prior to at least two moderate events in California, but these anomalies gave no information about the expected time of occurrence. An event in January, 1974, in Southern California, was predicted as to time and place, but the magnitude was substantially less than was predicted. In addition, post-earthquake analyses of seismic data have revealed evidence of precursory phenomena for many historical earthquakes.

The surface uplift (see Chapter II) along the San Andreas fault near Palmdale, and in Palm Springs, California, has led to an intensified interest in this area a possible site for a major earthquake. It is thought that the event could be large and similar in size to the 1857 earthquake. A velocity anomaly has been claimed for a part of the same general region.

Earthquake Prediction Research in the United States

The United States Geological Survey (USGS), Department of the Interior, has leading responsibility for earthquake prediction research in the United States. The Survey's Earthquake Hazards Reduction Program includes support of research through grants and contracts external to the Survey, and an active in-house program. In addition to prediction research, the program includes assessments of earthquake hazard through analysis of the geological setting of earthquakes, i.e., faulting and related tectonics, earthquake-induced geological hazards, and the prediction of ground motion generated by an earthquake. The National Science Foundation also supports basic science research on earthquake processes and earthquake engineering research.

The external contracts program of the USGS consists of about 35 contracts with two state agencies (California and Nevada), 13 universities, and three private research organizations. The nature of the research requires the support of a number of observational networks of seismographs and other geophysical instruments. The costs of equipment acquisition, installation, operation and maintenance are covered, though the funds available for support of research have been limited. The program includes geological and geophysical field studies, laboratory experimentation, and a small amount of theoretical modelling.

A large part of the Survey's in-house program of prediction research is based in Menlo Park, California. Major experimental study areas are along the San Andreas fault in central California, and on several active faults in Southern California, where the program is a cooperative one with the California Institute of Technology. In addition to seismic observations, the Survey has emphasized geodetic measurements including tilt, regional strain and fault creep, as well as other geophysical measurements.

Seismic networks are also deployed to determine regional seismicity and its relation to geological structure in other important seismic zones of the United States: Alaska and the Aleutian Islands; the Puget Sound area; California, Nevada, Utah; the upper Mississippi embayment; South Carolina; and the northern portion of the Caribbean Sea. The research program was provided more resources to propel the development of prediction technology when the Earthquake Hazards Reduction Act (P.L. 95-124) was enacted into law in 1977.

In relation to the law, the Office of Science and Technology Policy issued a report to be used in preparing an implementation plan. This report made several recommendations (Working Group on Earthquake Hazards Reduction, 1978, pp. SVI - XVII):

- The present procedure for evaluating earthquake predictions by the Federal Government should be continued. The Federal Government should provide an evaluation service at its discretion or upon the request of a Governor for those States which do not have this capacity.

- The membership of the USGS Earthquake Prediction Council should be formally expanded to include nongovernmental scientists so that the panel can be free of conflicts of interest, imagined or real, and can provide broad-based objective scientific evaluations. The Council should become the National Earthquake Prediction Evaluation Council.
- The USGS should continue to carry the major responsibility for issuing warnings (that is, predictions) about earthquakes, earthquake hazards, and any geophysical or geological anomalies that might constitute hazards.
- Definitions of terms pertaining to earthquakes such as "warning," "prediction," "alert," and "advisory" should be standardized as soon as possible. The USGS should take the lead in accomplishing this.
- An agency such as the National Oceanic and Atmospheric Administration (NOAA) should continue having prime Federal responsibility for issuing tsunami warnings and defining associated hazards.
- The special problem of predictions is foreign countries should be addressed.
- The responsibility for declaring an earthquake prediction or seismic hazard advisory as an emergency, or issuing a warning should rest with the State Governors. If State and local resources are inadequate to cope with the impacts of a prediction, Federal assistance should be sought under existing legislation or clarifying regulations.
- Each Federal agency should develop plans for taking appropriate steps, both within the agency and in their program responsibilities, after an earthquake prediction is validated. In addition, however, given the variety of seismic advisories and predictions than are likely to appear in the near future, a separate Federal evaluation panel is needed to assess the possible political consequences and action needs attendant upon a given prediction. Such a panel could aid in tailoring the responses of Federal agencies to specific situations. Governors of States in which federally funded prediction research is being conducted should be advised on a regular basis of the progress that is being made.

The establishment of the National Earthquake Prediction Evaluation Council was announced on January 28, 1980. To be composed of not fewer than eight federal and non-federal earth scientists, the Council will review data collected by other scientists and recommend to the USGS director whether a formal earthquake prediction or advisory is warranted. Organization of the Council implements the provisions of the Earthquake Hazards Reduction Act of September, 1977, and of a plan developed by a White House working group. The Director of the USGS issued two earthquake hazard watches in 1980: one for Mammoth Lakes, and one for southern California.

Earthquake Vulnerability and Human Adjustments

Global Earthquake Vulnerability

Earthquake activity is generally confined to three major belts (see Figure I-1), coinciding with the seams in the earth's surface where tectonic movements of the crust occur. The Circumpacific Zone extends around the entire land rim of the Pacific Ocean, along the coasts of South, Central, and North America, the Aleutian Islands and the Kamchatka Peninsula, through Japan and the Philippines to New Zealand. The second major belt lies across the mountain ranges of Asia and Europe and the Mediterranean Sea, and includes the Trans-Himalayan Zone, the Mediterranean Zone, and the Sunda Arc. The third belt is defined by the Undersea ridge system (Nichols, 1974). These three belts are not strict boundaries of earthquake activity; major earthquakes have taken place outside these zones, for example, the New Madrid (1811-12) earthquakes in the United States and the Konya (1967) earthquake of India.

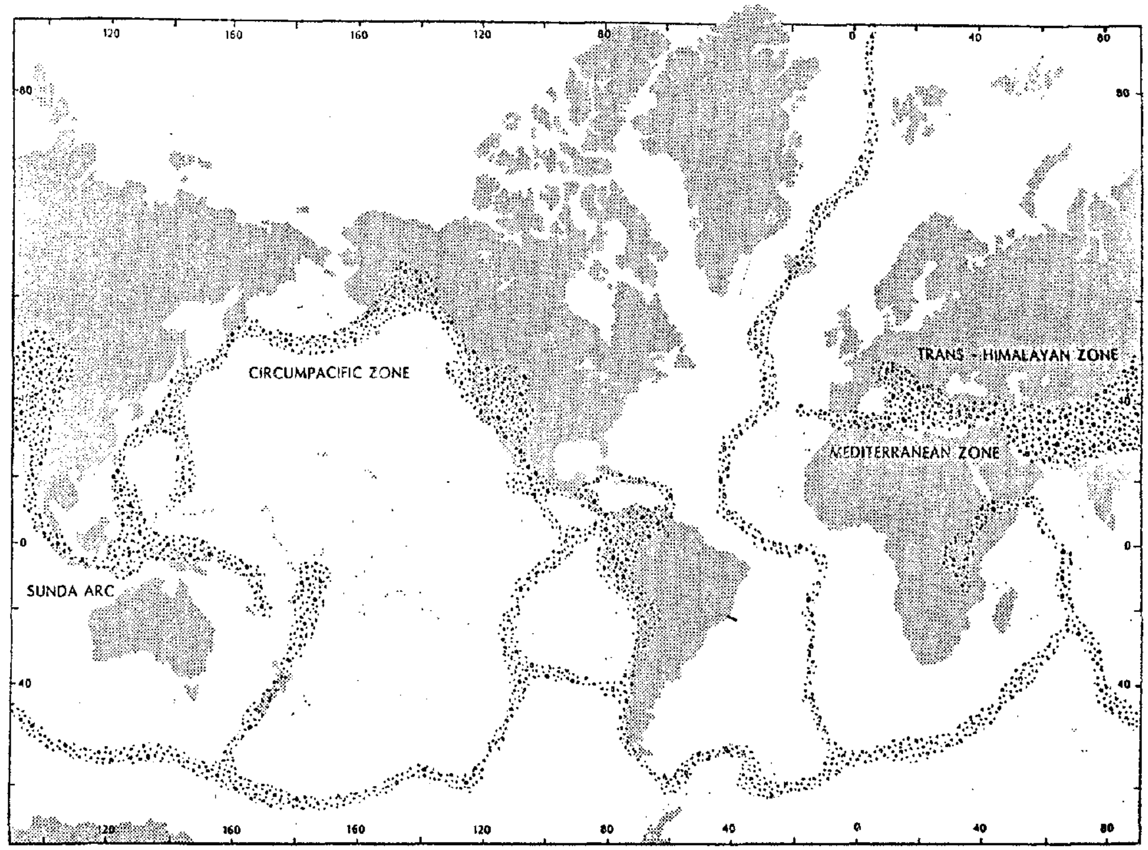
Global vulnerability to earthquakes is largely determined by the density of human habitation and settlement patterns in seismic zones. The greatest threats exist in heavily populated regions such as the west coast of the United States, the coasts of the Mediterranean Sea, Japan, the west coast of South America, the Philippines, China and central USSR. It is estimated that over 500 million of the world's people are vulnerable to some type of damage from the earthquake (OEP, 1972, Vol. 3, p. 72).

National Earthquake Vulnerability

No region in the United States is completely safe from an earthquake; however, major risk exists in areas adjacent to the San Andreas Fault system of coastal California, the fault system in east-central California separating the Sierra Nevada from the Great Basin, and the fault system along the southern coast of Alaska (Ayre, *et al.*, 1975). In this region the first credible prediction of a damaging earthquake in the United

FIGURE I-1

SEISMIC BELTS OF THE WORLD



States is most likely to occur. While there is the possibility for a disastrous earthquake in the middle or eastern United States, it is doubtful that this event would be among the first earthquakes to be predicted.

One approximate indicator of vulnerability is a seismic risk map (see Figure I-2). The levels of risk range from Zone 0 (no damage) to Zone 3 (major damage). These seismic risk zones, however, are crudely prepared, are not based on probable frequency of future earthquake occurrence, and only indicate levels of potential damage. When correlated with census data on the location of population, risk maps give some indication of the magnitude of the earthquake hazard in the United States. Over 186 million people, or over 90% of the nation's population, are vulnerable to some type of earthquake hazard. Of the nearly 31 million people living in Zone 3, the zone of major damage, over half are residents of California (Ayre, *et al.*, 1975).

The United States experience has been remarkably fortunate when viewed in light of national vulnerability to earthquakes. Only four events since 1900 have caused substantial destruction and loss of life. The likelihood of maintaining this record, however, is remote since catastrophe potential for the hazard is on the rise (Ayre, *et al.*, 1975). It appears certain that before the end of this century, one or more catastrophic earthquakes will occur on the North American continent. A worst-case extrapolation from the experience with the Alaskan (1964) earthquake suggests that in Seismic Zone 3 there may be the potential for 11,000 dead and $24 billion in property losses in the next 100 years (Kates, 1970).

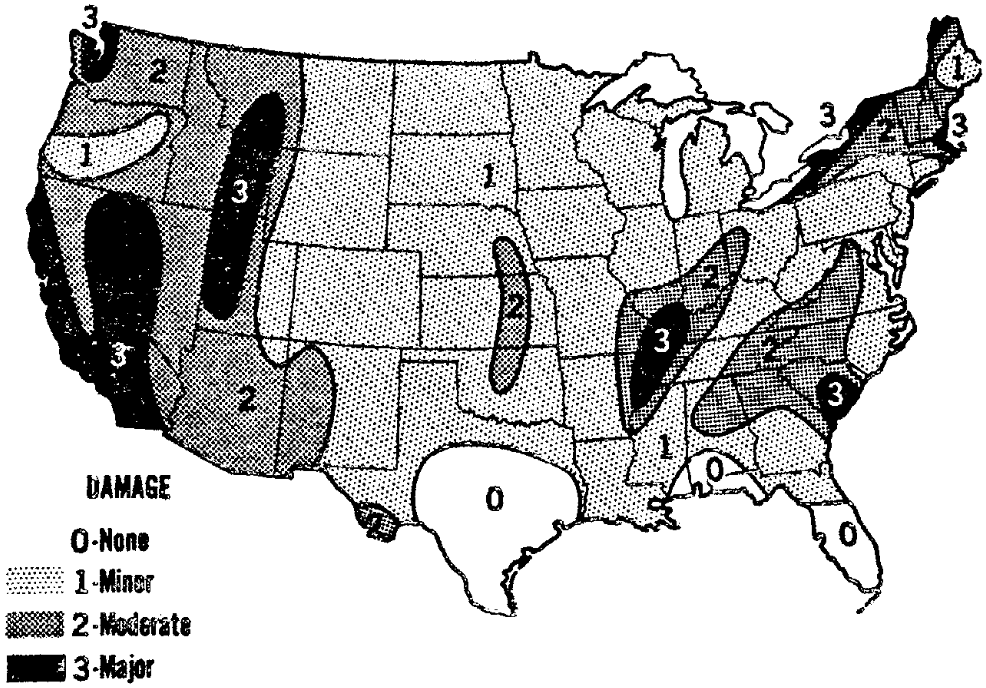
<u>Causes of Earthquakes</u>

An overwhelming majority of people, when asked about the causes of earthquakes, typically view them as either unaccountable or as an act of nature or God. Causes of disasters can be viewed as stemming from either

FIGURE I-2

SEISMIC RISK ZONES IN

THE UNITED STATES



(from S.T. Algermissen, *et al.*, 1969. <u>Studies in Seismicity and Earthquake Damage Statistics</u>, Appendix B. Washington: U.S. Department of Commerce.)

nature or technology (Burton, Kates and White, 1978). People and their decisions and habits are rarely viewed as causes of earthquake disaster. Earthquakes are natural events and the adverse effects can be mitigated by scientific research on natural causes. However, social, economic and political variables cause hazards too and need as much attention as physical and technical causes (White and Haas, 1975).

When it is accepted that earthquake problems stem from a combination of natural, technological and social causes, society will begin to assess and mitigate earthquake risk by using information about all three causes. At least five sets of forces or effects combine to determine the hazardousness of a place; the earthquake hazard is an interactive function of the following elements:

- Physical Effects
- Static Human Use Effects
- Systemic Human Use Effects
- Associated Hazards Effects
- Adjustment Levels Effects

Physical effects, which define the character of the earthquake event, are difficult to estimate because interactions among them are complex and difficult to predict. Earthquake damage may result from three separate sources: (1) strong ground motion (shaking), (2) surface fault ruptures, and (3) ground failure (landsliding, settlement, liquefaction). In turn, these effects are influenced by other earthquake parameters: (1) magnitude of the earthquake, (2) epicentral location, (3) hypocentral depth, (4) extent and magnitude of surface faulting, and (5) intensity and duration of ground motion.

To further complicate the attempt to evaluate local risk, a host of human use characteristics combine with physical effects. Included in risk evaluation are static estimates of the amount and distribution of exposure of people and various classes of structures according to age, use, type, height and density of occupation. Another element in estimating earthquake risk is that earthquakes sometimes result in compound disasters. Fires are the most common secondary hazard, although the dangers from flooding induced by, for example, tsunamis or dam failures are particularly important at some locations. Locally, landslides and avalanches must also be considered in risk estimates of earthquake hazard.

Future efforts to estimate the earthquake risk of an area should also consider indirect systemic effects. Geographic locations of especially vulnerable structures, systems or economic sectors whose demise would have implications beyond their direct damage are considerations. Losses like these appear to be a very significant cost associated with large earthquake disaster. An interesting study by Cochrane of losses from repetition of an earthquake in San Francisco of the same magnitude of that in 1906 indicates that indirect and systemic effects are, at a minimum, equivalent to direct property damages (1974).

Estimates of levels of mitigating measures in use in the area are also determinants of damage potential. Local capacity to respond to an earthquake emergency can greatly affect the influence of secondary hazards on damage levels.

Range of Human Adjustments

In its effort to cope with earthquakes, society has a variety of responses to the risk and the uncertainty associated with the hazard. Prediction and warning are only one means of reducing earthquake loss. At any given time, a subset of these alternatives is implemented by a society. Some adjustments are widely practiced, and others remain figments of theory. The theoretical range of human response to earthquakes is summarized in Table I-2. This classification, based on a conceptual model advanced by Burton, Kates and White (1978), suggests that humans

TABLE I-2

ADJUSTMENTS TO THE EARTHQUAKE HAZARD

PURPOSEFUL ADJUSTMENTS		
Choose/Change	Reduce Losses	Accept Losses
Change locations • Abandonment	Modify event	Share losses • Insurance • Disaster relief • Charity
Change use • Land use planning	Affect cause • No known way	Bear loss • Individual loss • Researve funds
	Prevent losses • Warnings, predictions • Emergency preparedness • Building codes • Engineering works • Evacuation	
INCIDENTAL ADJUSTMENTS		
Discount Loss	Reduce Losses	Choose Use/Location
• Tax deductions • Savings	• Fire codes • Transportation improvement • Fire fighting improvement	• Land use regulation; non-hazard specific
ADAPTATIONS		
Biological		Cultural
?		• Deurbanization (sprawl) • Shifts in aesthetic preferences • Shifts in family structure • Changes in wealth

(drawn from Burton, Kates and White, 1978) make subtle changes which are adaptive relations to earthquakes.

The principal means of changing land use is through management and regulation. For example, areas over fault lines slated for development can be zoned for low-risk use, such as parks or single-story frame housing. Change in location involves leaving the earthquake risk zone for an area of lesser risk. This may be an individual decision, or a wholesale abandonment of hazardous areas. Although there are a few examples of land use management for reducing seismic hazards, little has been done in the United States to encourage the application of this adjustment. A most encouraging example exists in the City of Long Beach, California, where a long-term program for phasing out the use of old and hazardous buildings is in effect.

The State of California has made two attempts to encourage recognition of seismic safety considerations in local planning efforts. The Alquist-Priolo Special Studies Zones Act aimed to guard against building inhabitable structures (except single-family dwellings) across active faults. Second, the California Council on Intergovernmental Relations adopted guidelines to be enforced under previous planning legislation which require California cities to take seismic hazards into account in their planning programs. The experience with both efforts is uneven and has been hindered by lack of data and by various interpretations of what is expected; however, the two pieces of legislation stimulated attention to seismic risk, and some useful actions have been taken despite the infancy of the technology.

An implication of sole reliance on land use schemes based on incomplete or technically poor information is that in consciously meeting the laws, decision makers can be lulled into believing they have adhered to all practical guidelines for safe location. Decisions to locate in areas of high hazard can be encouraged by guidelines which are either incomplete in their concept of hazard effects or inadequately implemented and enforced. Further study of the effectiveness of these laws is needed, as is continued research to improve the technology of assessing seismic risk.

Loss reduction may be achieved by modifying or affecting the cause, or by preventing losses from earthquakes. The hazard can be modified by improving site selections for construction and by reducing induced effects of secondary hazards associated with earthquakes by precautions such as slope stabilization or earthquake-resistant firefighting systems.

A variety of adjustments can prevent losses. With the development of techniques of earthquake prediction, event-specific warnings could inform the public of the approximate location, size and timing of an upcoming quake. Preparedness measures could include gearing up to provide emergency public services, medical assistance, or special planning for firefighting, vacating dangerous structures, and interruption of gas and electricity flows. Properly enforced building codes can make structures resistant to major destruction. Selective or total evacuation of risk zones immediately after or before impact could prevent losses from both the actual event and its induced effects.

It is impossible to abandon all national earthquake-prone areas permanently, or to reduce potential losses to zero. The residual losses must, therefore, be absorbed by society by either cost-sharing or cost-bearing. Losses are distributed by varied mechanisms such as insurance and programs of disaster relief. A somber fact is that the most common adjustment to earthquakes in the United States is individual loss-bearing.

Incidental adjustments are less obvious and more difficult to identify. A commonly cited example is that building code specifications for wind in Boston contribute to the seismic safety of that city. The most important incidental adjustments may come as responses to human-induced problems such as fire or urban transportation, which become vital elements in reacting to an earthquake and its consequences.

At this point, no biological adaptations have been identified or even hypothesized. It is certain that earthquakes have not caused long-term cultural changes which have enabled societies to adapt to the hazard; however, many changes in cultural patterns have resulted in new and different human risk relations to earthquakes. A prime example is urban sprawl which has spread the population-at-risk over larger land areas.

Interaction of Adjustments

A critical aspect in understanding human response to earthquakes is the interdependence among the varied adjustments to the earthquake hazard. Very few adjustments are effective in mitigating the negative effects of the hazard when employed singularly. Reducing risk is often dependent on a mix of several different adjustments applied in varying degrees. There are several possible ways in which adjustments interact. First, one adjustment adoption may causally influence the selection of a second adjustment. For example, studies indicate communities adopting flood control works often become reliant on federal relief and rehabilitation programs to cope with the effects of events exceeding the design magnitude. Second, a circumstance may influence the simultaneous or sequential adoption of two adjustments. In the U.S., the Flood Disaster Protection Act of 1973 provided incentives to communities to enter a flood insurance program and adopt land use ordinances. Additionally, certain forces may create sanctions against particular hazard adjustments. In the United States, for example, the prevailing cultural values of individualism and self-determination act as a constraint to the adoption and implementation of hazard-related land use controls. Some studies suggest other influences on adoption such as laws, regulations, bribes, hazard experience, education, resource level, hazard characteristics, or taxes (Burton, Kates and White, 1978; Sorensen, 1977). Finally, adjustments may interact in a random manner where no relationships exist between pairs or sets of actions. Such may be the case in Utah where seismic resistance is built into buildings, but because of religious beliefs, individuals stockpile food supplies which could upgrade disaster emergency response.

Microzonation

The technology for microzonation will enable the zoning of seismic risk in terms of very specific land segments, perhaps down to a block or lot. This information about seismic risk will enhance the ability to estimate the location, recurrence interval, and relative severity of future seismic events in a local area so the potential hazard can be assessed and effects mitigated or avoided (Cluff, 1978).

Armed with microzonation, comprehensive programs for earthquake hazard reduction in local areas could be designed and implemented. Accurate delineation of differential risk areas within a local jurisdiction can be used to stimulate the use of an appropriate mix of adjustments. Such studies have the potential to accomplish the following:

- improve design and application of practicable land use subdivisions and zoning programs;
- improve regional application of appropriate building design and practice;
- increase public awareness of risk from geologic hazards;
- improve emergency response planning;
- enable planning for compatible reconstruction after an event; and
- encourage socially appropriate response to earthquake warnings and predictions.

With the advent of the Earthquake Hazards Reduction Act of 1977, and the thoughtful development of a plan for implementing the law's provisions, comprehensive earthquake hazards management is in prospect. The plan emphasizes the need for balance in the use of hazard adjustments at the local level, and provides possible assistance to state and local governments.

Microzone studies have a tremendous contribution to make to planning efforts made by public and private managers to reduce the earthquake hazard. For microzonation to be most useful to local decision makers, the information needs to go beyond delineating soil and foundation data. Maps may include judgments about especially vulnerable segments of population, secondary hazard potential, and especially hazardous facilities and structures. More detailed information may better illustrate mitigation decision priorities to local decision makers, and the need for coordinating earthquake mitigation programs with other programs such as those of the California Coastal Zone Commissions, the National Flood Insurance Program, and the National Environmental Protection Agency. New programs may be instituted at the federal level for hazardous land acquisition or subsidized earthquake insurance. Ongoing microzonation efforts will allow communities a basis for informed participation.

Formal criteria are needed to determine the priority areas for microzoning earthquake effects. Early candidates for microzonation may be those places where growth has yet to occur rather than areas where population density is already high. Preventing incompatible development is cheaper than correcting existing facilities. If the new provision of information to local areas (under the Alquist-Priolo Act) is not accompanied subsequently by more detailed information, the current law could act as a deterrent to more comprehensive decision making. From the National Flood Insurance Program experience we have learned that general information may be worse in the long run than no information at all (Hutton and Mileti, 1979).

Earthquake Prediction Issues and Concerns

Social Utility of Earthquake Prediction

Research efforts in several nations continue to develop a technical capacity to predict earthquakes. The development and use of the technology are defined by many as worthwhile because of the promise it holds to reduce earthquake vulnerability, and to increase earthquake emergency preparedness. Both of these prediction goals exist independent of prediction technology and can be achieved in some degree by other earthquake hazard mitigation adjustments, such as building codes and planning. Earthquake prediction offers a new and potentially more successful means through which those goals can be achieved.

Earthquake prediction technology promises more specific information about the time, location and magnitude of an impending earthquake. It promises to provide the added specificity of hazard information on which can be mounted more intense efforts to reduce earthquake vulnerability and increase emergency preparedness.

The range of people that will be involved in making decisions about vulnerability and preparedness after a prediction currently have disparate levels of awareness about the kinds of decisions they will have to make. A prediction will generate much information, and this information will vary in accuracy, degree of completeness, and consistency. These mixes will create alternative expectations and mixed perceptions of level of risk by people faced with earthquake prediction decisions. The information available in a prediction setting can be somewhat controlled by policy. Appropriate public policy could help achieve the social goals for which the technology is being developed by anticipating the information needs that will exist after an earthquake prediction.

Some decisions to reduce vulnerability or increase emergency preparedness, even sound and appropriate decisions, will be hindered in implementation because of current prevalent constraints in the social system. Policy to mitigate these constraints will provide for more desirable choices by people and public and private decision makers if and when predictions are issued.

Reduce earthquake vulnerability. We refer here to decisions which speed up, intensify or initiate activities which lower the potential for loss of property, life, or money in some future earthquake. These decisions and activities range from taking pictures off the wall and packing away glassware, to structurally modifying a building to better withstand an earthquake, or in the extreme, to simply moving away. All such activities have two things in common: they reduce the potential for loss from earthquake impact, and an earthquake prediction need not exist in order for such decisions to be made and activities begun. An earthquake prediction would allow special decisions to be made that might be ignored under generic earthquake risk, such as temporarily lowering the water level in reservoirs, closing hazardous bridges, and temporarily evacuating particularly dangerous buildings.

Increase emergency preparedness. Increased capacity for emergency response, or emergency preparedness, refers to decisions and activities to reduce or redistribute the cost and anguish of immediate and long-range recovery after an earthquake. These decisions and activities include stockpiling emergency supplies, buying insurance, and developing disaster plans. Other decisions can be made on the basis of a prediction that would probably never be made in light of generic earthquake risk. These include, for example, moving emergency response equipment to the periphery of the target area, and having large-scale emergency response organizations locate and begin operations on the target area fringe prior to the earthquake. All these actions have increased the ability to respond to earthquake loss once it has occurred, and an earthquake prediction need not be made in order for such decisions and actions to be taken. Predictions, however, may not come without societal costs and problems.

Possible Negative Consequences

Earthquake prediction has been seen by some scientists and officials in terms of the potential it holds to cause negative economic, social and political impacts in a community or larger geographical area. These concerns are not unfounded. Information that a disastrous earthquake will occur in a community could elicit responses by some people or groups that could create negative secondary consequences or impacts. Concerns about negative impacts have been raised on a variety of issues: (1) what will happen to the availability of earthquake insurance? (2) will local property values decline? (3) will credit tighten for durable goods? (4) will the sale of durable goods decrease? (5) will mortgage money availability decline? (6) will local property tax revenues decline? (7) will construction fall off? (8) will there be a decline in local sales tax revenue? (9) will unemployment increase? (10) would there be a forced cut-back in local public services? (11) would some retail firms be forced out of business? (12) will there be a net decrease in local population? Affirmative answers to just a few of these questions conjure up images of a severely disrupted local economy, and make it easy to agree with those wishing prediction were only possible in the short term (one or two-day announcements), without enough time to affect an economy negatively.

Other legal and political questions are raised by earthquake prediction technology. For example, is an official liable for taking (or not taking) some actions in the public interest because of a prediction? How will a prediction affect the political process? What legislation is needed to put prediction to more effective use? Research can lead to timely changes in public policy to capitalize on the benefits, and minimize the potential costs, of earthquake prediction if and when the technique is used.

Generic Questions for Public Policy

Three issues are associated with public policy related to earthquake prediction: (1) how the information contained in a prediction can be used to increase emergency preparedness; (2) how a prediction can be used to decrease earthquake vulnerability; and (3) how policy can reduce the potential for negative secondary effects resulting from the knowledge that an earthquake may occur. These issues center on maximizing the utility of knowing ahead of time that an earthquake may occur, and of increasing the ability of the social system to respond to the earthquake disaster if it does. Efforts can be initiated or accelerated to increase emergency preparedness by people, families, business and government agencies. At the same time, a prediction could also provide the opportunity to reduce earthquake vulnerability, thereby actually reducing the extent of damage when the earthquake strikes. The challenge presented by the potential use and development of earthquake prediction technology in this country is to maximize benefits and minimize potential negative impacts.

Changes in the Time Parameter of Prediction

At the inception of the field work during which much of the data was gathered for the hypothetical prediction response study, earthquake prediction scenarios were designed on the basis of what seismologists thought earthquake predictions would be like if and when they were to occur in the United States. These scenarios reflected a high degree of credibility with a precise statement about place and magnitude. They were long-term predictions ranging up to a three-year period. Our hypothetical human prediction response data were developed on the basis of this long-term (three years) prediction. However, the dilatancy diffusion theory, which would be the basis for such long-term predictions, needs further testing and clarification. Seismologists currently view prediction prospects in terms of other evidence, and such predictions may be rather short in time frame, perhaps a few days.

There may well be too short a time between a prediction and the earthquake for many responses that are reported on in this work. This will have implications of two sorts. First, the full range of benefits will be harder to achieve given the short lead-time. Second, all possible negative economic impacts may not have time to develop. Nevertheless, the range of decisions and kinds of prediction responses in long and short-term predictions have been identified by our study of long-term prediction. Additionally, the reasons why some people may decide to follow, and others not to, a certain response behavior will likely be as applicable to a short-term prediction as long-term prediction.

CHAPTER II

EARTHQUAKE PREDICTIONS: EXPERIENCED AND IMAGINED

The purposes of this work are better understood in view of some predictions that have actually been made, and of those which can be imagined. This chapter provides a more colorful introduction to the critical issues of earthquake prediction and subsequent social response. It is intended neither as a systematic analysis, nor a basis for comparing experiences. It does, however, serve four purposes:

- To depict some actual past predictions. What have earthquake predictions been like? Who has issued them? Were they credible? These and other such questions are answered to give the reader an idea about how different predictions can be from one another.
- To illustrate the range of different behavioral response that can flow from a prediction. Have people believed earthquake predictions? What did public officials do? Did the public panic? What was done to reduce losses? Answers to questions like these begin to provide an image of the possible reactions that can follow an earthquake prediction. Many critical issues for public policy are linked to prediction response.
- To present what some officials would have done if they possessed prior knowledge of an actual earthquake. The most severe earthquake in the United States in recent years occurred in 1971 in San Fernando, California. City officials and business leaders gave their impressions to us about what they would have done beforehand were that earthquake predicted.
- To speculate on what a prediction and response to it could be like under an "ideal" set of circumstances. It is impossible to know ahead of time what the first few predictions of damaging earthquakes for populated areas in the United States will be like. Extensive interviews with seismologists, public officials and business leaders provided a story of one possible situation. The scenario presented is speculative and must not be conceived of as what will happen. It serves only to illustrate what some people thought about prediction response, the dependent variables on which much of our statistical analyses were performed, and a complex, albeit hypothetical, set of linkages and response sequences that could take place in a simplified and ideal world.

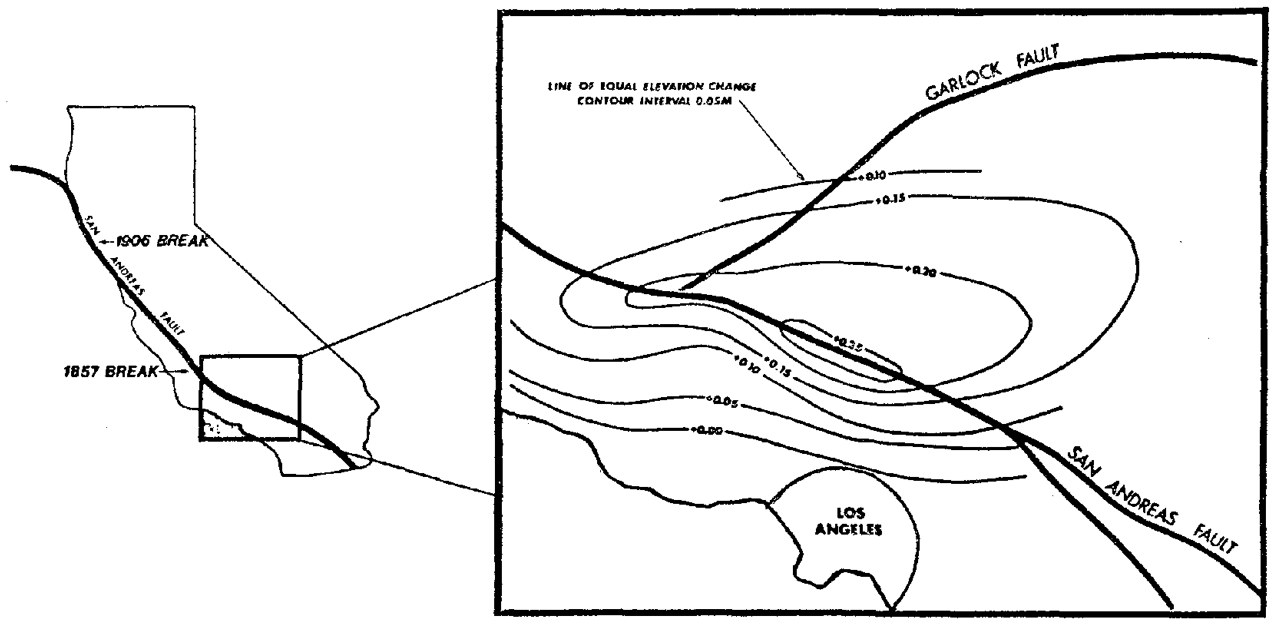
Five actual predictions are discussed. Four relatively credible in character were in Palmdale, California; Los Angeles, California; Haicheng, China; and the greater Tokyo-Kawasaki area of Japan. One prediction was less credible and made by a psychic for the Wilmington, North Carolina area. Two hypothetical prediction response examples are presented. The first is the result of asking the question, "What would government and business have done were the 1971 San Fernando earthquake predicted?" The second is one scenario of two which was used to obtain imagined response to a hypothetical prediction in our study.

The Palmdale Bulge

In early February of 1976, United States Geological Survey (USGS) scientists reported that a land uplift about 25 centimeters in height was detected along a rather large portion of the San Andreas fault in Southern California, just north of Los Angeles. The uplift was found to be centered near the town of Palmdale, in the western section of the Mojave desert (see Figure II-1). It was also reported that the uplift probably began in the late 1950's or early 1960's somewhere near the intersection of the Garlock and San Andreas faults. The uplift has since then enlarged toward the southeast and east; in 1976 it included about a 4,500-square mile area of Southern California, and in 1980 it covered 32,000 square miles.

The USGS stated that the uplift was not fully understood, that is, it may or may not be a precursor to an earthquake. The USGS, however, did express concern because the uplift had occurred along a section of the San Andreas fault that has been inactive since the great earthquake in that area in 1857. That earthquake has been estimated at Richter magnitude 8 1/4. The uplift could be caused by strain in the San Andreas fault that has been building up for over the 100 years since that earthquake occurred.

FIGURE II-1
THE PALMDALE BULGE



It was also noted that land uplift like that observed in the Mojave Desert has preceded earthquakes in the past, for example, the 1964 earthquake in Niigata, Japan. However, land uplift not followed by an earthquake has also occurred in seismic areas. The USGS decided that the uplift was insufficient evidence with which to conclude that an earthquake was due. Nevertheless, the uplift was sound reason to make the area one of intensive study to seek other precursors and anomalies. The USGS and scientists from some universities began intensive research in the area at that time. The USGS also thought their discovery significant enough to conduct a briefing with the Governor of California, Edmund G. Brown Jr., in March. Among the points made were the following (Manfred, 1976):

- While some evidence can be interpreted as precursory to a major earthquake in this region, there is no basis now for predicting the time it will take place. The sum of the evidence, however, justifies a warning that a great earthquake will take place in this area and also justifies preparedness actions.
- If an earthquake similar to that in 1857 occurred today in this region about 30 miles north of Los Angeles, the probable losses in Orange and Los Angeles Counties alone are estimated as follows:
    - 40,000 buildings would collapse or be seriously damaged
    - 3,000 to 12,000 people killed
    - 12,000 to 48,000 people hospitalized
    - $15 to 25 billion damage
- Failure of one of the larger dams could leave 100,000 homeless and tends of thousands dead.
- It is possible, but less certain, that one or more damaging earthquakes may take place within this region prior to a great earthquake.
- Studies of the area are underway by the USGS, the California Division of Mines and Geology, and several universities. Some additional instruments have been installed and new funds of $2.1 Million are to be provided in the 1977 Fiscal Year budget. Hopefully, a predictive capability will be developed in advance of the earthquake, but emergency plans should be developed on the assumption that there will be no advance notice.
- If data become available supporting a prediction in California, the evidence will be evaluated by the USGS and transmitted to the Governor.

At the same time, *The Los Angeles Times* (February 13, 1976) carried a feature article on the uplift. Some of this account of what was to become known as "the Palmdale Bulge" follows:

> A large and widespread swelling in the earth's crust has occurred in the San Gabriel Mountains and along the western edge of the Mojave Desert and is causing both concern and bafflement--but not anxiety--among seismologists and earth scientists.
>
> The concern is prompted by the fact that the uplift, to use the scientific term for this crustal bulging, lies on an approximately 100-mile-long stretch of the San Andreas Fault.
>
> The area involved is an oval of some 4,500 square miles, extending from Gorman on the northwest to a rather vague terminus around Wrightwood on the southeast. Palmdale is about in the center of the oval.
>
> Not only is the uplift straddling the San Andreas, it is doing so in nearly the same region where Southern California's last 'great' earthquake struck--the temblor of 1857.
>
> But for the moment, at least, no scientist is suggesting that the bulge is related to an impending earthquake and for this very good reason: no one knows for sure if it is or it isn't.
>
> 'We're mystified by it,' said James Savage, a U.S. Geological Survey (USGS) scientist in Menlo Park. 'There have been cases where there's been uplift in an area prior to an earthquake and there have been cases where there's been uplift and no earthquakes.'
>
> Barry Raleigh, another USGS scientist, said that an ancient Roman temple on the Italian coast near Naples is known to have sunk 18 feet below the waters of the sea and risen more than 18 feet into the air within the last 2,000 years--without any indications that earthquakes served as some sort of stage elevator.
>
> 'So it's fair to say that we really don't understand just what's happening with these uplifts,' he said.
>
> Nevertheless, because of the strong presumption that the bulge is somehow related to seismic activity, USGS and Caltech scientists are currently pushing for an expanded network of instruments to monitor the region very closely.
>
> Within the last few days, for example, USGS officials submitted to President Ford's Council on Science and Technology in Washington, D.C., a proposal calling for additional funds for the fiscal year starting July 1.
>
> The additional money would not only buy more instruments for the uplifted area but--and more importantly, in the eyes of earth scientists--would establish a comprehensive research program into the mechanics of earthquakes and the clues of an impending tremor.

In making their presentation, the USGS officials are understood to have stressed that the uplift may prove to be a rare opportunity to chart the life cycle of a major earthquake.

Curiously, the uplift is not exactly a new phenomenon. According to USGS scientists, it was discovered to have occurred for the most part between 1960 and 1964, with a sharp spurt in 1961-1962.

The crust swelled upward some 20 to 25 centimeters (8 to 10 inches) in some areas, principally around Palmdale and Gorman, and to a much lesser extent around the Wrightwood area. The evidence of the swelling was found in levelling reports filed by county surveyors.

To earth scientists like Dr. James Whitcomb, a senior research fellow at Caltech, this swelling pattern suggests one or two major possibilities.

One would be dilatancy, he explained, a process that would cause tiny cracks in subterranean rock layers to expand under stress and so increase the volume of the region. The stress, of course, would come from the action of the two land masses on either side of the San Andreas Fault trying to move past each other.

'Another possibility is what we call elastic deformation,' he said. 'We know that the North American continent is moving relative to the Pacific Ocean plate and the Big Bend (the area where the San Andreas Fault makes a dog-leg turn and where the uplift has occurred) is an obstacle to that movement.'

In a rough way, elastic deformation might be likened to the effect seen in a rug pushed against a wall--it piles up upon itself. It is tempting to think that this is what is happening in the uplifted area, since there is a more pronounced bulge at the northern end that at the southern, but the scientists again caution against jumping to conclusions.

The instruments that the USGS and Caltech have spotted throughout the area of uplift do not provide a simple and unambiguous picture of what is ahppening underground, according to Dr. Don Anderson, the director of Caltech's seismological laboratory.

Seismometers there disclose very little activity underground and the area seems stable, he said. And Savage said that a review of past surveyors' leveling records indicates that uplifting also occurred back in the 1900-1914 period without any concomitant earthquakes.

The scientists stressed that there was nothing that they could see in the uplift that suggested that an earthquake is now in an embryonic phase in the Gorman-Palmdale-Wrightwood area, let alone that it is imminent.

> 'We do know that Southern California eventually must experience another great earthquake,' said Anderson. 'It's inevitable. But we can't say right now when or where it will happen.'
>
> 'When seismologists talk about the earthquake that's overdue for Southern California, they tend to talk about something happening in the Bend region. That's where the last big one occurred, in 1857, and that's where you might expect the next one to occur. And that's why there's so much interest in this uplift. It may have nothing to do with an earthquake and it may have everything to do with one. We don't know. But we want to try and find out.'

After suggestions that uplift measurements were distorted by calibration errors or optical refraction irregularities, additional tests were undertaken to check earlier data. The USGS reported in December of 1980 that the Bulge "does exist" and is not significantly different in the size estimated earlier (USGS, 1980).

Studies to detect other possible precursors in the area have been undertaken. Investigations of radon in ground water, unusual water levels in wells, and microearthquake activity are underway. When combined with the detection of lessening strain on the southern San Andreas Fault, all the aforementioned anomalies continue to baffle and challenge geo-scientists (Kerr, 1980).

The Los Angeles Prediction

In April of 1976, a seismologist from a California University "predicted" that a 5.5-6.5 Richter Magnitude earthquake would occur in the San Fernando, California, area sometime within the next 12 months. He reported that variations in seismic velocity measured in the S to P wave ratio led him to conclude that an earthquake was imminent in an area some 87 miles in diameter, centered near the town of San Fernando. Newspapers in the area announced the "prediction" with front page headlines and subsequently published various articles on it.

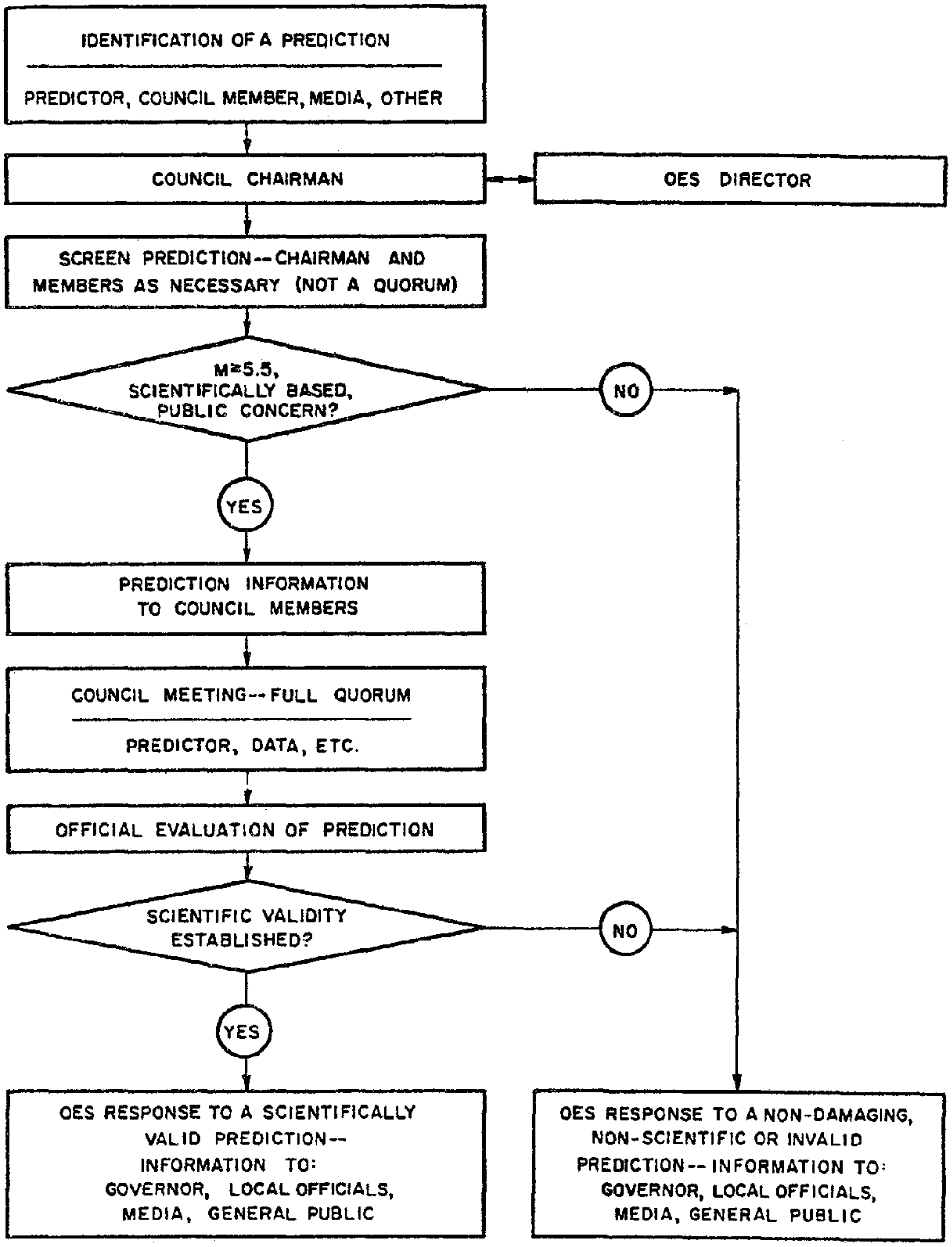
The scientist was cautious in his offering, firmly stating that it was a "hypothesis" test and not an actual prediction. To the media and the public, this distinction was not evident. Public officials responded with attempts to calm a slightly worried public by stating they were well prepared to handle the predicted event. It appeared that it was a situation to which many people did not know how to respond.

In the immediate period after the "prediction" was issued, few identifiable prediction-induced impacts surfaced. However, in the first week after the news was announced, some fears of adverse consequences were manifest. One member of the Los Angeles City Council sent the legal staff of the city into action to explore the legal implications of possible declines in property values. Some Los Angeles residents pursued information on the purchase of earthquake insurance. As a consequence, several larger insurors stopped or delayed selling new earthquake policies. One company cancelled earthquake coverage on all its homeowners' policies that were in force.

Public appraisals of and responses to the prediction were clarified by institutional mechanisms designed to determine quickly the credibility of the prediction and the seriousness of the threat. The scientific evidence for the prediction was submitted to the California Earthquake Prediction Evaluation Council for review. Using the procedure summarized in Figure II-2, the council concluded that there was not sufficient evidence to warrant an official prediction announcement. In late 1976, the author of the prediction indicated that new data had led him to conclude that the hypothesis ("prediction") had not been supported by the data. In effect, what had been described in the media as a prediction was then withdrawn.

In the wake of the Bulge and the prediction, a study was undertaken at UCLA in 1977 to ascertain the public awareness of the anomalies and predictions and its concern about the earthquake hazard. Preliminary

FIGURE II-2
THE CALIFORNIA EARTHQUAKE PREDICTION
EVALUATION PROCEDURE



findings were released in 1979 (Turner, *et al.*).

The Haicheng Prediction*

The most dramatic example of prediction success is illustrated by the events surrounding the 7.3 Richter magnitude event near Haicheng, China. This account serves to point out the great benefits that can be realized by predictions.

The prediction of the earthquake which occurred on February 4, 1975, began at least five years earlier when the State Seismological Bureau (SSB) targeted the Liaoning Province as a site with potential for a large earthquake. This area, therefore, became the focus of more intense investigation by Chinese seismologists. These examinations paid off when, in June of 1974, the SSB issued a more specific prediction. In light of studies of tilting and ground deformation, scientists felt that an earthquake of about magnitude 6 would occur in 1974 or 1975.

The more definitive statement led to increased geophysical investigation. In keeping with the national trend, several thousand amateur observation posts were established in the region to observe well water levels, animal behavior, radon concentrations in water, and magnetic and electrical phenomena. On the 20th of December, 1974, local governments were informed to expect a small (magnitude 5) shock. Two days later a magnitude 4.8 event took place in Liaoning Province, but further monitoring suggested a larger event was still imminent. This prompted the Provincial Revolutionary Committee to step up its efforts to warn and educate the public.

A revised prediction was issued on January 13, 1975, by the SSB, stating that a magnitude 5.5-6 event would occur during the first half of that

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*This account is drawn chiefly from Adams (1976), Bennett (1979), and Haicheng Earthquake Study Delegation (1977).

year in south Liaoning. Efforts to measure precursory phenomena were again accelerated and the public prepared to take adaptive actions.

Increasing seismic activity, a 4.7 magnitude foreshock on the morning of February 4, and anomalous well water and animal behavior observations led the provincial Revolutionary Committee to issue the alert for a strong earthquake to hit within a two-day time frame. Approximately five and one-half hours after the warning, the main event of magnitude 7.3 violently shook the area around and south of the city of Haicheng.

During that short period and the preceding two days, a remarkable degree of public preparedness and adaptive response was achieved. Despite the indications of a false alarm sometime in late December or early January, most people evacuated their homes to temporary shelters. Some records indicate many did so solely on the basis of their personal observations of unusual animal behavior. The impression is that when warned, almost everyone evacuated and cooperation was extraordinarily high. Movies were set up in outdoor fields to encourage the evacuees to remain outdoors in the freezing winter temperatures. In addition, relief and first-aid stations were quickly formed to assist potential casualties.

The benefits from the successful evacuation were enormous. In the city of Haicheng it was estimated that 90% of the buildings were destroyed or seriously damaged. While a few people who refused to evacuate were killed, many lives were saved (exact figures are unavailable, but it is estimated that the fatality toll could have exceeded 100,000). The role that the Chinese amateur program plays in encouraging adaptive response is well-documented. The large number of foreshocks provided valuable environmental clues to the public. The event occurred shortly after the warning; had it taken two or more days to manifest, the vigilence of the people may have diminished.

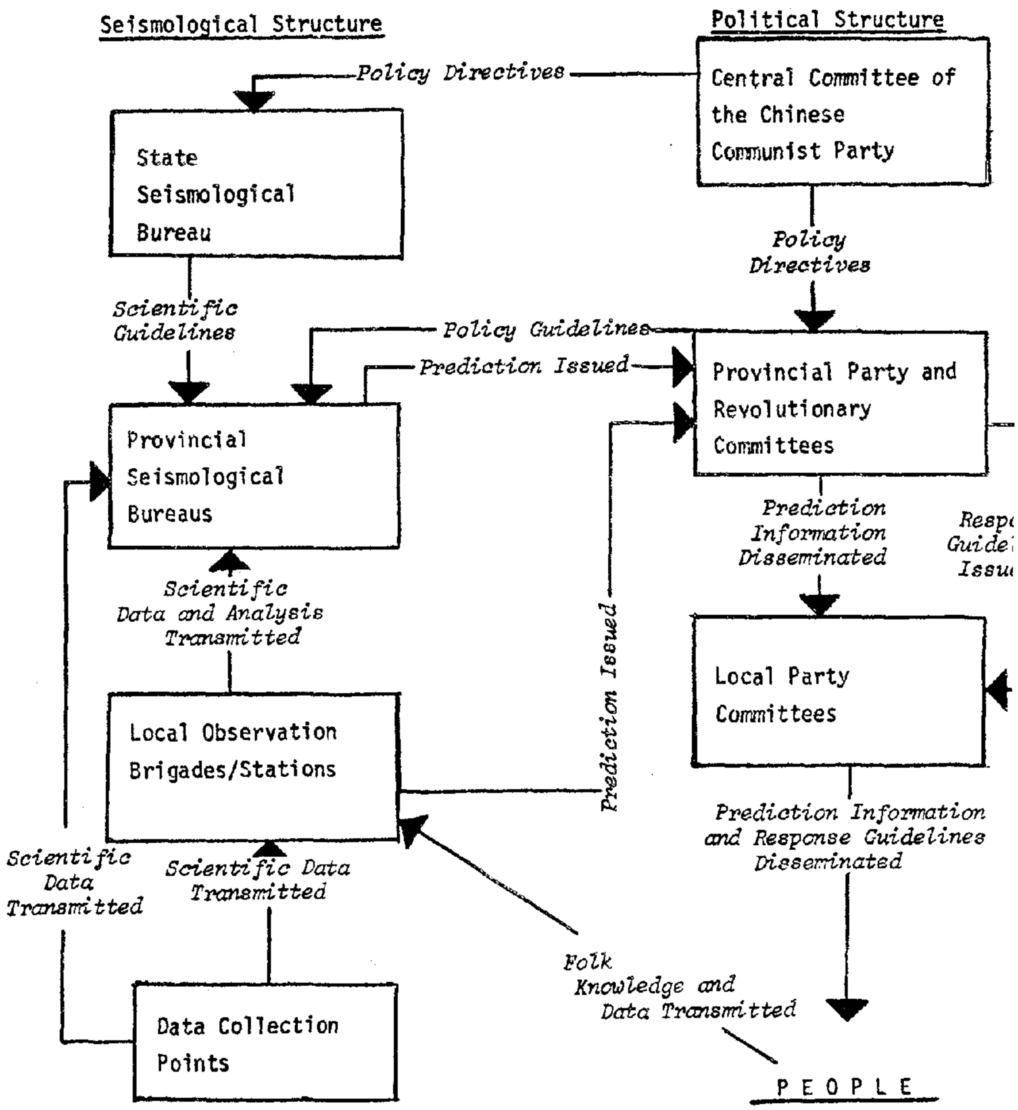
Reactions to warnings and predictions are likely to be different in

China than in other countries. Information available suggests that predictions are favorably received and respected by the Chinese population. This response is partly the result of the intense educational campaigns, the practical involvement of the people in the program, and the relationship of trust developed between laymen and experts, the people, and the government. Within the seismically active areas, the Chinese appear to have developed something of an earthquake culture (familiarity with the hazard, its consequences and a readiness to cope with them) which may be strengthened by repeated exposure to predictions and warnings.

The Chinese have not hesitated to issue warnings and evacuate people; they assume that if the earthquake does not occur, people will not resent the disruption the prediction has caused in their lives. Amateur participation in the prediction process is one reason why. A consequence of involving ordinary citizens in the prediction program may have produced public attitudes conducive to a favorable reception of warnings. On the other hand, all of the endangered Chinese public did not believe the warnings issued prior to the February 4 earthquake. There is no way to ascertain the extent to which those who died remained in danger because they did not believe the warnings. Awareness of this weakness in the program should not detract from recognizing the magnitude of the Chinese achievement, and current information leads us to hypothesize that people responded positively to the warnings. The Chinese prediction system is diagramed in Figure II-3.

The Chinese success has encouraged many; however, this success is viewed more soberly in light of the failure to predict the 1976 Tangshan earthquake which took a toll of over 650,000 lives. Nonetheless, the Chinese to have the ability to develop the technology and achieve favorable citizen response. From this brief examination of the Chinese experience four points seem crucial: (1) little is known about the social

FIGURE II-3
ORGANIZATIONAL STRUCTURE OF
CHINESE PREDICTION SYSTEM



aspects of earthquake prediction in China, particularly how the Chinese respond to a prediction and the attendant social and economic consequences; (2) it is difficult to assess how the Chinese experience can lead to specific recommendations for the United States earthquake prediction program because of the large economic and cultural differences between the two countries; (3) incorporating citizens into the prediction process and, in general, the decision process may enhance the utility of a prediction, although other consequences may be heightened or different consequences created by so doing; and (4) it would be valuable to gain more information on the earthquake predictions which have been issued in China.

The Japanese Prediction

In 1970, the ground in Kawasaki, an important Japanese industrial center, began to show signs of crustal deformation and upheaval. Members of the Coordinating Committee of Earthquake Prediction (CCEP) decided that the area should be monitored more intensely in order to determine if the upheaval were a precursor to an earthquake.

Instituted in 1969, the CCEP is comprised of 30 Japanese academic and governmental geophysicists. The CCEP continued to monitor the area closely and the land upheaval continued. The Committee then concluded that additional data gathering and study were warranted and that a request should be made to the national government for the added funding necessary to conduct the work. In late 1974, the committee recommended that the Kawasaki area of Japan be made a place of official intensified study for earthquake phenomena.

A few members of the CCEP, however, viewed the situation as more serious than did the committee as a whole. They wanted the available data made public. On December 26, 1974, after information had been leaked to a newspaper, the CCEP was forced to hold a news conference on the topic. It announced that a slowly developing, large-scale crustal deformation had been documented in the Kawasaki area. It also stated that while such upheavals are only sometimes associated with earthquakes, it was known that a similar deformation did exist prior to the Niigata earthquake in 1964.

The CCEP did not say that an earthquake was likely. However, in response to questions from reporters, a CCEP member did say that if an earthquake were associated with the upheaval, the earthquake would have a shallow epicenter, be of a 6.2 to 6.4 magnitude, and could occur about a year later, in late 1975 or early 1976.

Immediately after the press conference, some newspapers carried headline stories using the word prediction. Other newspapers and television and radio stations were more cautious, carefully reporting what the Committee had actually said and intended. Seasoned disaster journalists doubted that there would be only one precursor, crustal deformation, associated with an impending earthquake and reported the story factually.

Near the end of January, 1975, a national television network ran a three-part series which covered the opinions of scientists, earthquake prediction technology, governmental actions, and citizen response. The series indicated that the citizens of Kawasaki had begun to buy emergency supplies. The city government of Kawasaki began a series of meetings in each ward of the city to give advice and information to citizens. The meetings were well attended, by as many as 1500 people on some occasions.

Government reaction to the CCEP announcement was energetic; it acted as if it believed the "prediction." Two main considerations were behind this attitude. Many of the earthquake disaster preparations proposed in response to the Kawasaki affair were felt to be long overdue, so the government availed itself of the opportunity to do something about earthquake risk reduction. Furthermore, new budgets for the concerned agencies were due in February, 1975; the agencies had to act quickly after the December announcement to assure that they had requested adequate funds to cover the possible additional expenditures a disaster or response to the prediction might require. Many of the agency requests for additional funds were approved. Some new monies were allotted to earthquake damage prevention by the national government.

In spite of the controversy over the prediction, Tokyo officials also began to take precautions. The Disaster Countermeasures Agency, in the Tokyo city government, set up a team which consulted with relevant agencies in Kawasaki and Yokohama in order to establish guidelines for all agencies to follow. This team made assessments of expected damage, and developed plans and a budget for carrying out appropriate damage prevention measures. In mid-February, the Tokyo Metropolitan Government released its estimates of possible damage and proposals for action. The Disaster Countermeasures Agency had its budget increased over 25% in order to carry out and coordinate these activities.

The assumptions were that the earthquake would be an intensity 6 on the Japanese scale; the intensity 6 would occur within a 6 kilometer radius around the epicenter; and that there would be an area surrounding that which would suffer shocks of an intensity 5. There were actually two possible epicenters indicated on some damage maps early made public. One was located near the Kawasaki City Hall, the other in the Area of Kawasaki nearest to Tokyo. Consideration of wood housing types and the secondary hazard of fire led to estimates of 26,000 homes being destroyed, 150,000 people being affected in one way or another, and 44,000 people being injured. No estimates were made, however, of possible deaths. Government agencies in Tokyo used the projected epicenter nearest Tokyo as the basis for their plans of action.

The city government of Kawasaki assumed that the cpicenter would be near its city hall, and reacted even more intensively than did Tokyo. City officials, in response to citizen concern for building safety, drew up special damage prevention plans and submitted requests to get funds for strengthening old schools and building new ones. Kawasaki needed new schools anyway because of increased population. The budget requests were 30 times larger for this purpose than they had originally been. The national government subsidized the city of Kawasaki to research and plan for a segregation belt--an area of land to be purchased by the city that would contain a fire should it develop within the industrial area of Kawasaki. Such a belt would protect the residential area from a possible fire storm in the industrial area.

While no new employees were hired by governmental agencies to help with the disaster preparations, there were many internal re-assignments of employees within agencies to jobs of earthquake planning and information.

A study of citizen response done shortly after the loss estimates were released revealed that, of 2,200 households surveyed, a very high percentage knew of the prediction, but a very low percentage expressed much concern or worry. However, citizens were interested in knowing what government was doing to prepare for a possible earthquake, and were vigorous in expressing what they felt were the principal needs.

Some citizen groups organized to report their concerns to government agencies. The main worry was that a fire would spread to homes from the concentrated and highly volatile industrial area. Citizens thought the segregation belt was a good idea, but they had many questions about its design: how wide it should be, whether it would work, and whether it would be unsightly. Planning for such a belt or for alternative measures with subsidies from the national government continued for more than a year.

There was little evidence that citizens even considered leaving the Kawasaki area. There are several causes for the disinclination to evacuate: the Japanese are used to earthquakes, there is little opportunity for job change and subsequent geographical mobility, and there is really no place to go in Japan to escape the possibility of an earthquake.

There were a few slight economic consequences of the "prediction." Land values in Kawasaki stopped rising for a time, compared to a continued inflationary rise in other neighboring areas. It is not clear whether the "prediction" actually caused this effect, although we were unable to identify any other causes. There was also some evidence that real estate transactions slowed for a time. The sale of homeowners' earthquake insurance policies increased to about 8% at its peak in August 1975.

In response to governmental activities and to citizen concern for preparedness measures, most business organizations stepped up emergency planning and trained their employees in emergency measures. Some earthquake disaster simulations were held to assure that employees knew what to do. Departments within businesses responsible for emergency planning did not receive more money; they reallocated annual funds to address these new earthquake concerns.

A major train company began a concerted effort to inspect bridges, piers and embankments for safety. The company has subsequently reinforced one bridge and planned to reinforce another that was found to be questionable. On the whole, business organizations, like governmental agencies, used the prediction as an opportunity to speed up already existing plans for disaster response and preparation. Most felt that whether the prediction was correct or not, earthquake disaster preparation was desirable.

In May of 1975 the CCEP announced that there was an alternative explanation for the crustal upheaval. For about a decade large quantities of water had been pumped out from under Kawasaki for industry, and there had been gradual subsidence in the area during the 1960's and into the early 1970's. In the early 1970's, continued pumping of underground water was prohibited, and the subsidence finally stopped, to be followed by swelling in the areas that had subsided. The crustal upheaval, therefore, could very well be just a reflection of the slow increase in the water table. This alternative explanation apparently created considerable doubt for those who previously viewed the crustal deformation as a likely earthquake precursor.

In August 1975, the CCEP announced that further studies showed an absence of other precursory phenomena such as changes in the velocity of seismic waves, horizontal strain of the earth's crust, and the radon content in well water. The committee concluded that it was quite unlikely that the upheaval indicated an earthquake. Most officials, regardless of their earlier beliefs, decided that Kawasaki was no longer the focus of a scientific earthquake prediction. An earthquake such as that anticipated by some in the Kawasaki area has not occurred to date.

Psychic Prediction

Psychic predictions lack the added dimension of credibility given predictions by seismologists who are members of the scientific community. For most people, predictions made by psychics are less believable.

In early January, 1976, a psychic predicted that a major earthquake (8.0 on the Richter scale) would strike the Wilmington and Southport areas of North Carolina sometime between January 13th and 20th, 1976. The prediction made the front page in the Wilmington newspaper on Sunday, January 11th. The prediction was confirmed, in a sense, by a professor of geology at University of North Carolina, Chapel Hill. He commented that the psychic's prediction was in agreement with his own scientific findings, and that she had successfully predicted the dates of three other earthquakes in the recent past. The professor was in the process of publishing a paper which presented his own conclusions. In the paper he predicted that a Richter 8 magnitude earthquake would strike the area between Wilmington and Calabah, North Carolina, sometime in the next decade. The comments of the Chapel Hill geologist and those of half a dozen other experts were given wide publicity; however, all the other specialists attempted to discredit the psychic's prediction.

This "prediction" was specific as to the time, place and magnitude of the expected earthquake. Despite the obvious credibility problem, the prediction, to some extent, did alter the normal course of life for some people in the area. About 30% of the population were concerned enough to seek additional or confirmatory information about the prediction. While churches did not report any change in attendance, about 40% of the businesses contacted reported a decline in either the number of customers, total sales or both. The strongest effect of the earthquake prediction, however, was in the sale of insurance. Because of the prediction, about 6,000 earthquake insurance policies were sold by the 85 agents or agencies in the area. In addition, in the midst of the initial flurry to purchase earthquake insurance, three national insurance firms refused to sell any more policies; one other severely restricted its sales.

The earthquake did not occur, but because the prediction did elicit some response, it was possible to document what people thought about the prediction, what they did, and what explained differences in response patterns. The following observations are based on interviews with a randomly selected sample of 181 families in Wilmington and its environs, and questionnaire responses by businesses, insurance firms, and churches.

The family response data gathered overwhelmingly illustrated that most persons in the area were well-informed about the predicted earthquake: 94% of the families in the population knew when it was to occur; 89% knew where it was to occur; and 69% knew how big it was expected to be. Belief in its occurrence, however, was quite a different matter.

When questioned, 72% of the respondents did not see the earthquake prediction as credible in even the slightest degree; the remainder had "mixed" feelings on the topic. This seems to be supported in that about the same percentage of respondents, 71%, did not actively seek any additional or confirmatory information about the prediction, while 29% did. This suggests that a little under 33% of the population were taking the prediction at all seriously. It also is consistent with much of the existing knowledge on disaster warnings--that warning or prediction belief is intrinsically intertwined with warning confirmation behavior.

When asked if they believed that the predicted earthquake would occur sometime in the next week or so, 91% of the families said no and 5% said yes. Three percent were undecided. Ninety-two percent of the sample believed that "a damaging earthquake is possible--in your lifetime."

Respondents were asked to estimate what chance they gave that the earthquake would occur: 45% said that there was a 0% chance; 40% said that there was a 1%-10% chance; and 15% said there was a 11%-85% chance. It is significant that 55% of the respondents believed that there was some, albeit in some cases slight, chance that the earthquake would occur. This is important in explaining what families did in response to the prediction. It was found that 8% of the families bought earthquake insurance within the first week after the prediction, two families evacuated, 40% took varied other actions to protect their families, and 17% stockpiled emergency supplies.

An explanation for family responses involves three general considerations: 1) knowledge of or perceptions about the parameters of the prediction itself; 2) actions taken in response to the prediction; and 3) reported influences on decisions about response to the prediction. Findings indicate that only perceived credibility of the prediction was significantly related to believing that the earthquake would occur. There was a relatively strong correlation ($V = .39$). We then determined what affected the perceived credibility of the prediction. We found that social class was negatively correlated ($V = -.19$) with the perceived credibility of the prediction. The lower a person's social class, the more likely he or she were to see the prediction as credible. Education was positively related to accurate definition about the content of the earthquake prediction ($V = .18$). It also held that whites had more accurate definitions than non-whites; the correlation was $V = .29$. These findings suggest that the lower a person's social class the more likely he or she were to be confused or misinformed on this earthquake prediction.

Two factors were significantly related to the purchase of earthquake insurance in response to the prediction. Education of the head-of-household was positively related to this adjustment ($V = .21$), while religiosity was negatively related to the adjustment ($V = -.22$). Education of the head-of-household was also positively related to actions to protect the family ($V = .23$). Education of the head-of-household and occupation of the chief wage earner were also positively correlated with taking protective actions at work in response to the earthquake prediction. Respectively, the correlations for these relationships were .24 and .34.

Only one factor, age, was significantly related to what people said influenced their decisions about what to do in response to the earthquake prediction. The variable of influence was divided into an internal or external locus-of-control where items such as God or fate were deemed "external" and those such as science or facts were deemed "internal." No matter how age was measured, older persons were more influenced by external factors, and younger persons were more influenced by internal factors. Respectively, correlation coefficients for all three tables were .26, .28, and .27.

All churches reported that there was no change in the counseling of parishioners. No churches held any special meetings because of the prediction. When asked if the prediction had any special impact on the congregation, 50% responded that the only impact was that the prediction was the topic of conversation. Attendance at church services, however, was affected by the prediction. About 17% of the churches responding reported that church attendance was not substantially different on the weekend during the time window of the predicted earthquake; however, 33% reported about a 10% increase in attendance, while 50% reported some sort of decrease in church attendance which ranged evenly from a 1%-18% decrease.

The businesses sampled were asked a variety of questions in an effort to detail the effect of the earthquake prediction on local business activities. We found that, for the period of the predicted earthquake, no special items sold particularly well because of the earthquake prediction, business hours remained the same for all businesses, and sales remained unchanged. Only two business organizations in our sample purchased earthquake insurance.

In the week preceding the earthquake prediction, 43% of the businesses sampled reported some reduction in sales; 10% reported a sharp decline in sales; and 33% reported a slight decline in sales. Thirty-eight percent of the businesses sampled also reported a reduction in the number of customers served during that time period; 5% reported a sharp decline over the previous week while 33% reported a slight decline. The decline in the number of customers served ranged from 2%-25%.

The sale of insurance was most strongly affected by the earthquake prediction. Our estimate indicates that about 6,000 earthquake insurance policies were sold in response to the earthquake prediction, by the 85 agents or agencies in the area. Responses indicated that 90% of these policies were added to existing policies; only 10% were for new clients. Coverage sold ranged from $4,000-$50,000. On the average, coverage ranged from $11,000-$31,000 for households. Premiums ranged from $2-$1200, with an average of $18.50. Of all insurance sales, 94% were residential policies, and 6% were for commercial buildings.

Some perceptible patterns existed among those who purchased insurance. Obviously, most purchasers were those who could afford to buy policies. Interestingly, only 3% of the companies in the study reported selling any earthquake insurance policies after the date of the predicted earthquake. In the midst of the initial flurry to purchase earthquake insurance, three national insurance firms refused to sell any more policies, and one severely restricted sales.

Consistent with much of the literature on natural hazards warnings (cf. Mileti, 1975), it was found that many persons who believed the prediction were still reluctant to translate that belief into a threat which was immediate. The vast majority (92%) of respondents believed that such a threat could be real in the future.

In general (see Table II-1) socioeconomic status was positively related to taking adjustment behavior in response to the earthquake prediction. This finding is particularly interesting when viewed in concert with other findings. Social class was negatively related to the perceived credibility of the prediction, and indirectly negatively related to belief in the occurrence of the earthquake; however, it was positively related to taking adjustment behavior. In other words, persons of higher social

TABLE II-1

RESPONSE IN WILMINGTON: A SUMMARY OF SIGNIFICANT RELATIONSHIPS

Variable Pair	Chi Square	Sign.	Interpretation
Perceived Credibility and Prediction Belief	28.51	.001	As the perceived credibility of a prediction increases, people are more likely to believe the earthquake will occur.
Perceived Credibility and Social Class	6.42	.05	People of higher social class are less likely to believe a psychic's prediction is credible.
Education and Accuracy of Knowledge	12.68	.01	Those people with higher education are more likely to have accurate knowledge about a prediction.
Race and Accuracy of Knowledge	15.28	.001	Whites (versus non-whites) are more likely to have accurate knowledge about a prediction.
Education and Purchase of Earthquake Insurance	8.13	.01	People with higher education are more likely to purchase earthquake insurance.
Religiosity and Purchase of Earthquake Insurance	8.92	.01	Religious people are less likely to purchase earthquake insurance.
Education and Adoption of Hazard Adjustments	10.24	.01	People with higher education are more likely to take other earthquake adjustments.

class were *less* likely to believe that the earthquake would occur, but *more* likely to err on the side of caution by taking adjustment behavior. At the same time, persons of lower social class were more likely to believe that the earthquake would occur, less likely to have the information about the prediction correctly perceived, and less likely to have done anything to reduce their risk.

Hypothetical Prediction for San Fernando, 1971

In February, 1971, a 6.5 Richter magnitude earthquake struck in the vicinity of San Fernando, California. To ascertain the view of the public officials and business persons about earthquake policy issues, we created a new and hypothetical decision context. In light of their experience with the 1971 earthquake and their wisdom gained from reflection, persons were asked what they would do if they had known this event was going to happen, and the types of constraints they would likely encounter. We conducted the interviews in order to learn what experienced persons though they could do with an earthquake prediction. We used their answers to develop grounded questions for subsequent hypothetical prediction studies.

Their responses provide a detailed picture of what decision makers might do should there be a prediction. Some example actions, in response to this hypothetical prediction, given by business and government officials follow:

Business

- assess vulnerability of physical plant
- consult with headquarters
- store emergency equipment
- alter content and schedule of work
- reinforce safety of physical plant
- notify employees and public about what to do
- close down for the earthquake
- transfer some employees
- move records
- develop a cash reserve
- reallocate priorities

- develop emergency plans
- arrange to get help from other companies
- coordinate with government
- gather more information

Government

- assess vulnerability of buildings
- step-up emergency plans
- educate public
- reallocate priorities
- reposition emergency equipment
- delay capital improvements
- increase inter-agency communication and coordination
- meet with state and federal agencies
- legislate additional funds
- selective evacuation
- after planned spending
- assess legal implications
- learn how to fill out federal government forms

Scenarios

Preface to the Hypothetical Prediction

There are many good reasons why this scenario, or any scenario built on conjectured response to a hypothetical set of circumstances, should be used advisedly. The social sciences have long issued cautions against reifications in conceptual development and scenarios. There are, however, fewer caveats about constructing hypothetical systems or sets of sequential causes, affects and outcomes. Such systems are known by such names as models, games, simulations, uptopias, ideal types and scenarios. The methods guiding their building are as varied as are their titles. They have been employed alone and in combination. The constructor of such social "realities" may be an ancient Greek oracle, a contemporary social scientist or an engineer; the method employed may be based on positivism or universalism; the product may be called a game, model or scenario; nevertheless, each system is appropriately labeled a utopia.

Contemporary utopian techniques have produced a voluminous set of theses (scenarios) in the name of policy research. Like more traditional utopias, scenarios have looked to the future as well as the past (cf.

Ericksen, 1975); they have been optimistic as well as pessimistic. Most often, policy-related scenarios are explications of possible social futures. Most begin with alternative events or social changes and end with descriptions of their consequences after large skips through time; they are sometimes based on descriptions of dynamic processes. Intuition, creativity or bias often play a greater role in the creation of alternative future scenarios than any established empirical base. Projections of unknown futures are affected by factors which cannot be taken into account; however, they can give adequate indications of probable actions in the future (see Appendix I for further discussion).

The scenario about to be presented is the result of interviews conducted with organizational and family respondents during our hypothetical response study.* Chapter III describes how this scenario was developed, and the sequencing of categories of respondents. The scenario was a research tool. It was designed to give respondents a possible set of economic, social and political events associated with a prediction, as a context in which to conjecture hypothetical response. The scenario is not a set of research findings; it is a composite of respondent conjecture built upon conjecture. The scenario is presented here for review as a research tool. It is divided into four time periods that extend over the three years of a hypothetical earthquake prediction. Each time period suggests revisions in the scientific parameters of the prediction, and subsequent response in the social, economic and political systems. The research was done in 1975-76, so the dates in the scenarios were then in the future.

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*This scenario was built through the efforts of many members of the research team; however, major authorship belongs to J. Eugene Haas.

The Scenario--Time Phase One

In July of 1977, the Director of the U.S. Geological Survey announces that a specified urban area of California is being designated as an area of intensive study of possible earthquake precursor data, anomalies having been detected there over the past six months. Timely notice will be given if there is a significant probability of an earthquake occurrence. The Director makes it clear that this is not an earthquake prediction. When contacted, two reputable, nongovernment seismologists say that their interpretation of the data convinces them that there is a 25% probability of a damaging earthquake in the designated area (along a major fault) in approximately three years (1980).

- The news media immediately report that the "intensive study" announced by the USGS will mean placing more monitoring instruments in the area to get better measurements of what is happening in the earth's crust.
- City and county officials say there is little immediate cause for worry. News media reports, however, make it clear that local officials responsible for public works and construction are seeking advice from state agencies as to what to do if the situation becomes more serious.
- Some people in the area seem to be taking the prediction seriously; others express skepticism. Many from both camps contact experts for their opinions.
- Some homeowners in the area buy or attempt to buy earthquake insurance for the first time.
- Both homeowners and businesses begin to check on the safety of their premises, and to review their internal emergency plans.
- A local newspaper series on earthquake prediction says:

    a. successful earthquake predictions have been made in other countries;

    b. many lives were saved by the prediction of a large earthquake in China;

    c. some small earthquakes have been predicted in the United States;

    d. a certain number of earthquake predictions have been wrong; and

e. economic experts say an official earthquake prediction would hurt an area's economy.

- Eleven months after the USGS announcement, in the early summer of 1978, population growth in the "target" area changes as does new construction starts and new business openings.

The Scenario--Time Phase Two

In August of 1978 the U.S. Geological Survey releases the first official prediction of a damaging earthquake.

There is substantial evidence that an earthquake of magnitude 7.0 or greater will occur in September or October two years hence (1980) in the designated area. Its occurrence is rated as 50% probable.

- Immediately after this official prediction, the Governor of California announces that the California Earthquake Prediction Evaluation Council has examined the USGS data and agrees with the prediction. The Governor directs state agencies to prepare for the possible earthquake; the federal government directs its agencies to do the same.

- Although some local government officials express doubts about the accuracy of the prediction, nearly all say that city and county departments will take appropriate action.

- Within a few days of the official USGS prediction, news reports indicate that a majority of scientists find the prediction believable, with a small minority insisting that accurate predictions are not yet possible.

- Shortly after the official prediction, the State Insurance Commissioner rules that new earthquake insurance policies can no longer be sold in the "target" area, although policies already sold will remain in force. Insurance companies and mortgage lenders begin to call for some type of federal insurance program to keep property values from dropping.

- By September 1978 most local newspapers have published maps of the area showing where earthquake damage is expected.

- California engineering firms begin to advertise that they will inspect buildings and recommend alterations to make them safer in the event of an earthquake. Some homeowners in the "target" area contract for evaluations of the structural integrity of their houses; and some business firms begin to contract for such evaluations.

- Government agencies begin safety inspections of public buildings and dams.

- Some government agencies issue pamphlets on safety measures.

- As a consequence, some homeowners begin to improve the safety of their premises; many do the work themselves, but some hire construction firms or carpenters to do the work.

- The official prediction has immediate effects on construction within 25 miles of the predicted center of the earthquake as some new construction work planned is not begun, construction work already in progress continues.

- Lending institutions operating in the "target" area reduce the number of loans they are making in the area. New loans still being made require higher down payments, fewer people can qualify for loans, and property becomes difficult to sell.

- By March 1979, seven months after the official prediction, there is a slight decrease in city sales tax revenues, and city officials begin to plan for the necessary cuts in services. Long-term planning for the city is drastically revised.

- By the summer of 1979, evidence indicates that a few families are postponing large purchases.

- Few people are withdrawing savings and reinvesting them outside the "target" area, many more are putting more, not less, money into savings accounts in area financial institutions.

- By the summer of 1979 many people say they are considering moving out of the "target" area permanently; but no one actually does so.

- In August 1979, the U.S. Congress begins considering a federal insurance program for the area of the predicted earthquake, because of economic problems already occurring there.

The Scenario--Time Phase Three

In late November of 1979 the U.S. Geological Survey revises the earthquake prediction. The earthquake is now said to be 80% probable; it will occur during September of 1980 with a 7.1-7.4 Richter magnitude.

- News media reports indicate that most local officials now believe the prediction, and are calling for agencies at all levels of government to take appropriate action.

- The Governor, stating that California has inadequate funds to meet the emergency, seeks a Presidential Emergency Declaration to provide money for special preparedness measures, and to cope with severe economic problems in the threatened area.

- Many employers, both public and private, begin urging employees to plan vacation leaves for September 1980.

- More area residents begin to make plans to leave (evacuate) temporarily, but about 50% still plan to stay.

- Retail sales of major goods, like refrigerators, drop as more people in the area decide to delay major purchases.

- Local and state governments speed up their planning for action before and after the earthquake, and intensify their public information drives to familiarize citizens with necessary safety measures.

- Dams and fuel lines are inspected by the State; plans are made to partially empty reservoirs of questionable safety by mid August 1980.

- In the early summer of 1980 some private and governmental offices, operations and equipment are moved out of the "target" area temporarily:

    a. businesses begin taking measures to protect their stock, and some move vital records and sensitive equipment out of the area;

    b. some large industries announce plans to close down in September to protect employees;

    c. schools announce that their fall opening will be postponed;

    d. a few national business firms move their branch facilities and operations out of the area permanently; and

    e. increasing economic pressures force many small businesses in the area to close their doors; by the end of 1979 one-fourth of them have either declared bankruptcy or sold out;

- By the early summer of 1980 some families in the "target" area have increased their insurance (fire, property, medical, and/or life) since the prediction was first made. There is increasing citizen interest in whether or not the U.S. Congress will pass legislation for federally subsidized earthquake insurance.

- By now the majority of the population is planning emergency procedures and precautions, and is stockpiling food, water, medical, and other supplies. About one-eighth of the families in the area have moved some of their possessions elsewhere, and many have taken steps to secure valuables and important documents within their homes.

- Business activity is decreasing, forcing many firms to lay off employees, which in turn is further slowing the local economy. However, local businesses and chambers of commerce are assuring the public that despite some economic problems, the area and its businesses are basically sound.

- Law enforcement departments, fire departments, and water departments request extra money for preparedness measures. Cities and counties, unable to levy taxes to meet the requests, cut funding of libraries, parks, recreation, trash collection, and street cleaning in order to increase funding for more vital services.

- Some people in the "target" area are still ignoring the earthquake prediction, according to polls of citizen attitudes which the news media keep running regularly.

<u>The Scenario--Time Phase Four</u>

In early July of 1980 the prediction is updated once again by the U.S. Geological Survey. The quake will occur during the first week of September 1980, with an estimated magnitude of 7.3. The prediction is still thought to be 80% probable.

- Preparedness efforts are speeded up, with local government officials urging evacuation of high-risk areas, especially those below some reservoirs, and planning police and fire protection for empty houses and buildings (although total protection cannot be guaranteed).

- Daily traffic patterns in the area change dramatically. Congested ubran areas and areas with highrise buildings also have less traffic than usual. Shopping is much less, except that for food and other necessities, as is patronage of theatres and recreation centers. Attendance at religious services and social activities falls off. Half of the parents of school children say they will not send their children to school; the schools do not plan to open for the fall.

- In August 1980 a Presidential Emergency Declaration is finally announced for the area, and government and business leaders use the resulting allocations of federal funds to take further preparedness measures, and alleviate the more pressing economic problem in the area.

- The Red Cross and other agencies establish shelters and stockpile them with supplies to accommodate residents who will leave their homes immediately before the time predicted for the earthquake.

- Some supermarkets and other retail stores announce they will stay open during the predicted earthquake period of the first week in September.

- The Governor orders National Guard units into the area, in readiness to assist local authorities.

- Hospitals and prisons in the area transfer their charges to safer locations.

- Some overpasses and bridges are closed, and detours through safer areas established.

- Some residents, whether they plan to stay or to leave temporarily, turn off their gas and electricity. They secure objects in storage areas and tape windows. The Red Cross, the city government, and other governmental and private agencies are swamped with inquiries.

- As more and more people leave during the last two weeks of August, many businesses close down completely, and many buildings are vacated.

- By the end of August some of the local residents have left the area for vacation trips or to stay with relatives or friends. Even more have moved some of their possessions to safer locations.

- Withdrawals from savings institutions increase to cover the cost of evacuating.

- There is little employee absenteeism at businesses and offices which have decided to stay open during earthquake week; thorough precautions have been taken to protect employees who are continuing to work.

- People express concern about looting, and some refuse to leave the area because of this fear. Law enforcement departments and the National Guard do all that they can to prevent looting.

- One week before earthquake week, all public buildings are vacated, records in these buildings having been previously relocated or specially secured. To maintain critical governmental operations, skeleton crews operate out of trailer-type facilities located well away from buildings and power lines.

Summary

Table II-2 summarizes important aspects of the predictions discussed in this chapter. While these are diverse experiences, several generalizations may be drawn. First, predictions, at least as the technology develops, will not be as precise as the scenario prediction. Even in Liaoning the parameters remained vague. Second, it does not appear that early predictions will be made in quantitative probabilistic terms, but with more qualitative statements. Third, the situations underscored the need for a better understanding and monitoring of the social and economic systems. This last generality we deal with in this work.

In addition, these situations point to a myriad of policy-related issues and questions. Palmdale indicates a need to develop sound and wise

TABLE II-2
A SUMMARY OF PREDICTION CHARACTERISTICS

Event	Reputation of Source	Confirmation of Prediction	Certainty of Threat		Intensity of Threat	
			Probability	Location	Magnitude	Timing
Kawasaki, Japan	Good (geophysicists from CCEP)	Little (media emphasized lack of scientific consensus)	None given	Uncertain; 2 possible epicenters 6 km radius	Unofficially 5 or 6 intensity on Japanese scale	A year later; no window given
Wilmington, NC	Mixed (psychic-poor geologist?)	Almost none (geologist and psychic agreed; all other geologists disagreed)	None given	Specific	Specific (8.0)	Specific lead time; time window 1 week
Los Angeles, CA	Good (university seismologist)	None (California earthquake Prediction Evaluation Council did not confirm)	None given	Moderately specific; epicenter in 87 mi. diameter area	5.5-6.5	Lead time and time window indeterminant; 0-12 months
Liaoning Province	Good (experts, amateurs and civil authorities)	Present-both by experts and folk signs	None specifically given; implied high	Specific region	Strong	Lead time and time window varied from 2-year period to finally 5 hrs
Hypothetical Prediction	Good (USGS)	Present (other seismologists and California Earthquake Prediction Council)	50-80%	Specific	7.1-7.4	Lead time 3 years; time window: 2 months; later 1 week
Palmdale Bulge, CA	Good (USGS)	Some	None given	Specific	Unclear but probably large	None given
San Fernando, CA	Good (USGS)	Present	100%	Specific	6.5	9 month lead; 1 week window

means of disseminating public information. Whitcomb's "hypothesis" for Los Angeles illustrates the problems of confirmation and establishing public credibility. The successful Haicheng prediction raises many questions but, perhaps foremost, whether other countries can learn from this experience. The events in Japan lead to a broader question on whether false warnings will lead to greater preparedness or to the "cry-wolf" syndrome. Wilmington's experience suggests that socioeconomic factors may influence the propensity and ability of people to take adaptive response. The discussions with people in San Fernando show that predictions can and will be of great benefit to a community. Finally, the prototype scenario demonstrates well the complexity of the problem at hand: understanding responses to a future event is not easy.

The next chapter explores the latter issue and reveals the limitations of this line of research.

CHAPTER III

METHODS OF STUDYING HUMAN RESPONSE TO EARTHQUAKE PREDICTION

The Problems

The scientific study of human response to earthquake prediction is riddled with problems. The most obvious is that it is difficult, if not impossible, to study human response to an event which has not occurred. There are major obstacles to scientifically accurate research, each in some way related to the lack of actual prediction situations to study.

One of the main obstacles is that we cannot be sure of the character of an actual prediction. An earthquake prediction contains variables important to human response. Some, discussed in Chapter IV, are the amount of lead time between the prediction and the anticipated earthquake, the reputation of the person or organization making the prediction, how certain the predictor is about whether the earthquake will occur and where it will occur, and how much consensus there is among seismologists about the characteristics of the prediction. If any of these change, human response will change.

The ideal study of human response to earthquake prediction would be to observe an actual prediction and its characteristics (P^{1}, P^{11}, P^{111}), and then to observe actual human response (R^{1}, R^{11}, R^{111}). It is difficult to speculate on future human response (R) even if the characteristics of the prediction (P) are known; it is even more difficult to speculate on human response (R) without knowing the character of the prediction (P). This approach would require a large number of actual predictions in order to establish statistically valid relationships.

Another uncertainty is the chance that the nature of causal system factors will change over time. For example, holding the characteristics of an earthquake prediction constant, we could project that 10% of a citizenry would stockpile emergency supplies on the basis of a current study. However, it is very likely that stockpiling is facilitated by surplus capital and that the extent of surplus capital in a citizenry changes over time. There is no way to know how much surplus capital will exist if and when an actual prediction emerges.

Social system changes of a different magnitude may also be important. For example, further normalization of relations between the U.S. and China may encourage U.S. adoption of Chinese ideas about earthquakes and affect response in a subtle manner. Changes in government organization, such as the formation of the Federal Emergency Management Agency (FEMA), can alter the political climate for guiding response, as can changes in elected officials and appointed personnel.

A third major source of uncertainty is the interrelatedness of response. One person's response may be predicated on someone else's action. For example, the government may need to authorize the use of funds before local officials could take extensive precautionary action. Or, the person who purchases earthquake insurance may not do anything to secure household possessions.

Behavior is also related to social values, technological development, and the pattern of earthquake adjustments adopted by society. To some extent, behavior will reflect prevailing social values, which are subject to change. Furthermore, technological advances interact with possible social responses to predictions. For example, new earthquake-resistant building techniques, improved building materials, better mass transit, or personalized mass communication may encourage behavior which is different from what we would predict at this time. Very sophisticated earthquake hazard reduction techniques could lessen greatly the need for preparedness, but it is best to view prediction in terms of current earthquake adjustment technology.

Previous experience with predictions raises another uncertainty. Persons may have been in an area for which a prediction is offered, or have been exposed through the media to a prediction elsewhere. For example, the "Whitcomb" hypothesis or the "Palmdale Bulge" could affect how persons in Southern California will respond to a future prediction. Information about prediction success and failures on small quakes, or the experiences in other countries such as China, will also have a bearing on future response. To guess about the sequence of learning and actions is difficult.

It is reasonable to expect that response will be influenced by cultural and locational factors, although the extent is unclear. Response to a prediction issued in the U.S. but outside of California would probably be different from response to one issued for the San Francisco area. Likewise, response could differ between Southern and Northern California, which have distinct cultural settings. On a larger scale, it would be impossible to infer that what happens in China would apply to Japan. On the other hand, there would be useful lessons that transcend cultural differences and can be universally utilized. The Chinese experience with amateur seismologists provides a good example (Turner, 1978; Ward, 1978).

It is easier and probably more accurate to estimate response to a prediction in the immediate future than to one five to ten years away. The further away an earthquake prediction in time, the more difficult it becomes to study the responses of a complex social system.

Finally, what people say they will do and what they do often differ. Uncertainties are introduced into any study in which behavior is asked about rather than observed.

Minimizing the Problems

These problems and uncertainties should not prohibit research into human response to earthquake predictions. Though they make it difficult to state conclusively the course of events after any given prediction, meaningful questions can be addressed by current research and techniques that can lend confidence to the findings can be designed.

One strategy to study human response to earthquake prediction before any actual predictions emerge is to examine human behavior in an analogous situation, such as a flood warning or how people responded to the warnings of the April, 1979, incident of radioactive releases at the Three Mile Island nuclear power plant. Transferring knowledge from a situation in which behavior can be observed to an uncertain situation has great merit. For example, there is information about response to other hazard warning systems, and generalized findings may be applicable, to some extent, to the earthquake hazard.

Studies still can be successful in the discovery of what factors will influence people's future decisions and behavior.

Data Sources

The analyses, interpretations, and findings in this study work are based on various sources of social data. Sources are in matrix form in Table III-1. Four general situations provided a context for response. First, although the ideal situation is to observe actual responses to a credible prediction, circumstances did not permit this except for limited secondary information from the experience in China with the 1976 Haicheng earthquake. Second, it was possible to use data on actual responses to predictions that did not receive widespread support. The three situations examined were Whitcomb's "hypothesis" for Los Angeles, a prediction for Wilmington, North Carolina, by a psychic, Clarissa Bernhardt, and a prediction in Tokyo which failed to get scientific endorsement. Brief summaries of each of these events were presented in Chapter II.

TABLE III-1
A MATRIX OF DATA ON PREDICTION RESPONSE

	Type of Data								
	Secondary Data Observation			Informal Interviews & Discussion			Formal Questionnaires		
Societal Level→	Citizens or Families	Business Leaders & Organizations	Public Officials & Agencies	Citizens or Families	Business Leaders & Organizations	Public Officials & Agencies	Citizens or Families	Business Leaders & Organizations	Public Officials & Agencies
Actual Response to Credible Prediction: China	Yes ✓ 1	No	Yes ✓ 2	No	No	No	No	No	No
Actual Response to Other Predictions: Whitcomb Wilmington Tokyo	Yes ✓ 3 ✓ 4	Yes ✓ 5 ✓ 6 ✓ 7	Yes ✓ 8 ✓ 9 ✓ 10	No	Yes ✓ 11 ✓ 12	Yes ✓ 13	Yes ✓ 14	Yes ✓ 15 ✓ 16	Yes ✓ 17
Hypothetical Response to Real Situation: San Fernando	No	No	No	No	Yes ✓ 18	Yes ✓ 19	No	No	No
Hypothetical Response to a Hypot. Situation: SB-Riverside Santa Clara State of CA Tokyo	No	No	No	Yes ✓ 20 ✓ 21	Yes ✓ 22 ✓ 23 ✓ 24	Yes ✓ 25 ✓ 26 ✓ 27	Yes ✓ 28	Yes ✓ 29 ✓ 30 ✓ 31 ✓ 35	Yes ✓ 32 ✓ 33 ✓ 34 ✓ 36

Footnotes for Table III-1

1. Includes various reports and accounts of prediction response in China.

2. See Note 1.

3. Includes newspaper accounts of situation and conversations with local observants.

4. Includes accounts from the local newspaper and field observation.

5. See Note 3.

6. See Note 4.

7. Includes field observation in Tokyo.

8. See Note 3.

9. See Note 4.

10. See Note 7.

11. Personal interviews with insurance agencies.

12. Interviews with 9 businesses, 3 unions, and 1 newspaper in Kawasaki and Tokyo.

13. Interviews with 16 government agencies in Kawasaki and Tokyo.

14. Random sample of 200 families in Wilmington area drawn from the city directory. 181 interviews completed.

15. Mail questionnaires sent to churches, businesses and insurance agencies. Twenty percent of the churches were mailed questionnaires, and 13 of 25 responded (56%). The same sampling fraction produced 24 returns from 81 businesses (30%). The entire population of 85 insurance firms were included with a 70% return.

16. The organizations in Note 7 were administered formal questionnaires.

17. The organizations in Note 10 were administered formal questionnaires.

18. Included 10 interviews with businesses and media organizations in San Fernando, California.

19. Included 13 interviews with local government officials in San Fernanco.

20. A random sample of 260 families in Santa Clara County, California.

21. Included discussions with 8 seismologists in California plus numerous individuals not representing a government or business organization.

22. Included 19 local businesses, in San Bernardino and Riverside, California.

Footnotes for Table III-1 (continued)

23. Included 19 local businesses in Santa Clara County.

24. Included 37 regional and national businesses operating in California.

25. Included 22 public officials and local and county agencies in San Bernadino and Riverside, California.

26. Included 19 public officials and local and county agencies in Santa Clara County.

27. Included 31 state, federal and private organizations dealing with public health and welfare, and 30 to 40 key individuals in state and federal government.

28. 243 of the random sample of 260 completed formal questionnaires.

29. Formal questionnaires were given to 19 local businesses.

30. Formal questionnaires were given to 19 local businesses.

31. Formal questionnaires were given to 37 businesses.

32. Formal questionnaires were given to 22 local government officials and agencies.

33. Formal questionnaires were given to 19 local government officials and agencies.

34. Formal questionnaires were given to 31 state and federal officials and agencies.

35. See Note 16.

36. See Note 17.

The third sort of situation involved a hypothetical response to a real situation. In this instance, we asked various people and organizations in San Fernando what they would have done if they had known the 1971 earthquake were coming in advance of its impact. The final situation involved hypothetical responses to hypothetical predictions. Most of the available data on prediction response are of this type. Responses to several different predictions were surveyed in two local areas in the U.S. (San Bernadino-Riverside, and Santa Clara County, California), and for the State of California in general. To a limited extent, additional data of this nature were collected in Tokyo and Kawasaki, Japan.

The hypothetical response data were collected by use of a scenario-building technique. Because organizations and people, in an earthquake prediction setting, would respond not only to the prediction, but also to the response of others, it was necessary to ask about conjectured response in the context of the response of other parts of the social, economic and political systems.

Groups interviewed were divided into seismologists; major news media; national health, safety, welfare and government agencies; national business corporations; local news media; local health, safety, welfare and government agencies; local businesses; and, finally, families. All seismologists were interviewed first, and the results of those interviews were summarized into a prediction scenario. That scenario was presented to major news media. The anticipated coverage response of those media was then incorporated into the prediction scenario. That revised and expanded scenario was then presented to the large health, safety, welfare and government agencies interviewed. In this way, each subsequent group was presented with a larger and larger context in which to respond.

The final scenario was presented in Chapter II. This scenario was divided into four time periods so that hypothetical family prediction response could be questioned throughout the three-year hypothetical prediction period.

The order in which groups were interviewed and the scenario constructed was designed on the assumption that each subsequent group would be affected by the behavior of prior groups more so than by the behavior of subsequent groups. There was no empirical basis on which to establish the order of the groups; however, the sequencing decided upon is a reasonable one.

The three general social system levels--families and individuals, private organizations and businesses, and public officials and agencies--can be further refined into specific groups. Private organizations included businesses localized in one community and ones which operated on a regional or larger basis. Organizations were chosen in a nonrandom purposeful fashion to give a diversity of function and purpose. The range included local newspapers as well as large television stations, and corner pharmacies as well as multi-national conglomerates. Public groups and officials included those at the local, county, state and federal governmental levels, and various non-governmental organizations.

In addition, several different types of data-collection techniques were utilized. In some instances, secondary data and unsystematic field observations were all that available resources permitted. Informal interviews and discussions were conducted with individuals and spokespersons of organizations. Formal questionnaires were also administered. In some cases, several techniques were utilized with the same sample to enhance data reliability. In addition, data from informal interviews were utlized to construct questionnaires and scenarios of alternative prediction possibilities. These scenarios provided a context in which the respondents could answer the structured questions on earthquake prediction response. The formal questionnaires included questions on response and a wide variety of background data on the organizations or families in the samples.

In a later chapter some of the relationships which help explain response are discussed. Table III-1 and its footnotes have more detailed explanations and descriptions of the data.

Techniques of Analysis

Given the wide variety of data types used in this work, more than one single method of analysis was utilized. Those employed are best discussed in relation to the different types of data collected.

Little in the way of systematic analysis was performed on the secondary data collected. It was used chiefly as background information and to provide a descriptive picture of events and situations. To a minor extent, content analysis of newspaper accounts was conducted, as in the case of the *Los Angeles Times'* reporting on the Whitcomb "hypothesis".

Informal interviews provided much information on response to earthquake predictions. The data were examined by the use of non-quantitative classification techniques. For example, responses from organizations in San Fernando (Table III-1, Footnotes 18 and 19) were placed on cards which were examined for common dimensions and concepts. From this analysis a response typology was generated which provided the basis for developing the more formalized response questionnaires in the study.

Second, data were arranged and worked into speculative scenarios of possible prediction situations. The scenarios were utilized as research tools to help respondents conceptualize a hypothetical prediction situation (this was done in connection with the data collected in Table III-1, footnotes 20 to 27).

In addition, rough forms of content analysis were selectively applied. For example, the interviews with public officials (Table III-1, footnotes 22, 23, and 24) were analyzed to determine agencies' perceived responsibilities for conducting vulnerability assessments of buildings and other structures.

Quantitative statistical analyses were made with the data collected through structured questionnaires (this included Table III-1, footnotes 14, 28, and 29 through 34). Similar procedures were used for the data from private organizations and public agencies (29-34), Santa Clara families (28), and Wilmington households(14).

The organization data consisted of a set of dependent variables measuring intended responses to a hypothetical prediction, and independent variables measuring organizational characteristics. Descriptive aggregate statistics of all dependent and independent variables were compiled. Next, zero-order Correlation Coefficients were produced for most pairs of independent and dependent variables. This was done for all organizations taken together, and then for a number of subgroups, such as local government agencies and officials, or non-local businesses. This pointed out which independent variables were associated with each category of hypothetical response.

The correlation analyses provide the grounds for then determining the relative importance of the associations between independent and dependent variables. Multiple regression techniques were utilized to assess the strength of the relationship between each dependent variable and all independent variables which were significantly correlated to it. Further types of multivariate analysis were conducted, but do not provide the analytical basis for this report.

The family data also consisted of a set of dependent variables on hypothetical response, and independent variables describing family characteristics. The procedure for analysis was almost identical to that for the organizations.

CHAPTER IV

PREDICTION-WARNING DISSEMINATION AND RESPONSE

In this study, we propose a model of the human response to earthquake prediction. The model conceptualizes what our research leads us to conclude are the predominant social processes that a prediction could affect. This model is presented in Figure IV-1 and explained in subsequent sections of the chapter. The model begins with an earthquake prediction.

Earthquake Prediction and Warning

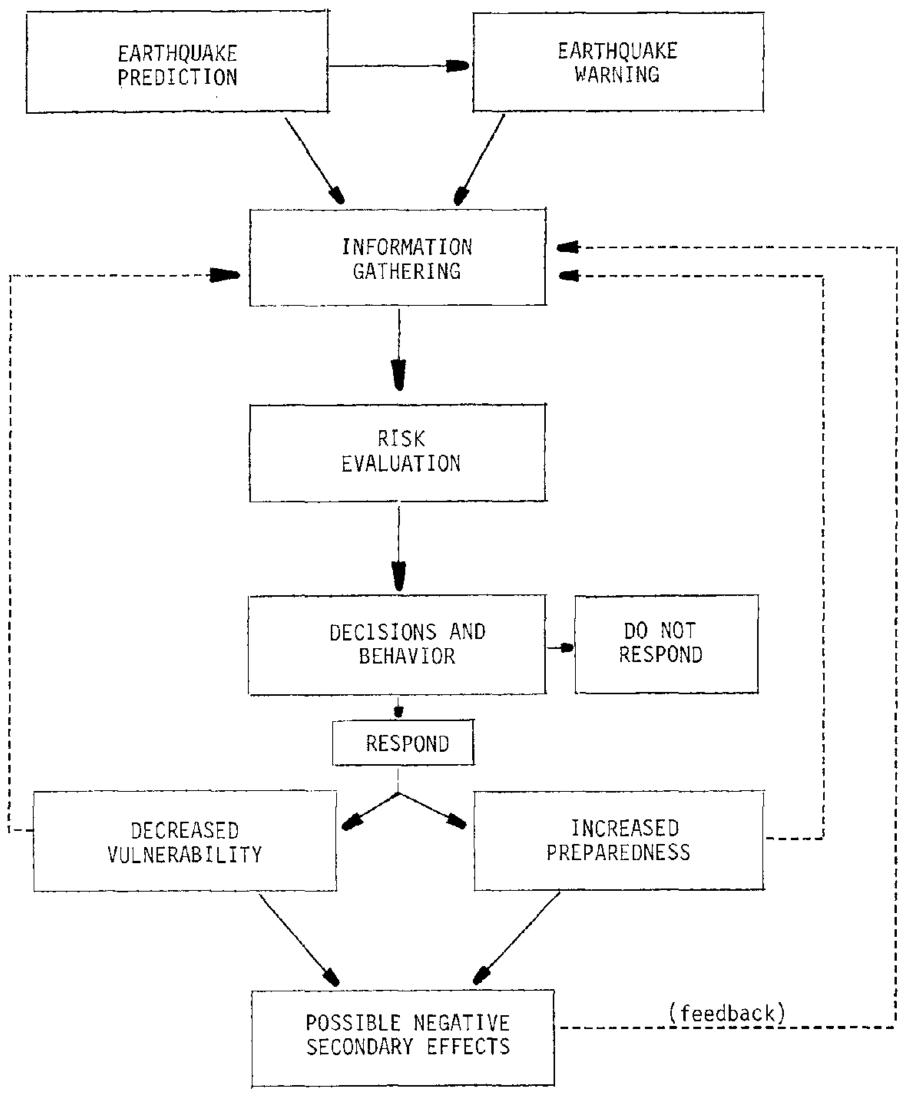
Earthquake predictions and earthquake warnings are not the same. A prediction is a declaration that earthquake occurrence probabilities may be changed: an earthquake is perceived to be more likely to occur in a place within a more specific time window than previously thought. The Panel on Earthquake Prediction (1976) defined a prediction in terms of six parameters. Ideally, a prediction coming from a scientist should contain the following:

- Lead Time--a statement about how far in the future the earthquake will occur
- Time Window--a statement about the time period in dates between which the earthquake will occur
- Magnitude--a statement about the size (measured on the Richter or similar scale) of the predicted earthquake
- Location--a statement of the geographical area in which the earthquake epicenter will occur
- Impact--a statement about what damage will occur
- Probability--a statement about the likelihood or confidence that the first five parameters will occur as specified

A warning, on the other hand, is a recommendation for appropriate public action in response to the perceived state of nature. Predictions and warnings have been defined by the Panel on the Public Policy

FIGURE IV-1

A GENERAL SOCIAL PROCESS
MODEL FOR EARTHQUAKE PREDICTION



Implications of Earthquake Prediction (1975, p. 47): "A *prediction* is a neutral statement that accumulated observations seem to signal more or less clearly the occurrence of an earthquake of a specified magnitude at a specified location and time. A *warning,* on the other hand, is a declaration that normal life routines should be altered for a time to deal with a danger impending or at hand." However, many people, including public officials, may not appreciate this distinction between predictions and warnings.

In concept, there is little difference between earthquake predictions and warnings, and between predictions and warnings for several other dramatic event natural hazards. Earthquake warnings involve the same three basic functions of a warning system: (1) evaluation of physical information about the threat, (2) dissemination of threat information, and (3) human response to the threat (Mileti, 1975, p. 11). In Los Angeles, for example, most people are quite able to admit that "earthquakes happen here", and in Miami most people readily agree that "hurricanes happen here." A hurricane prediction--"there is a tropical storm off the coast of the southeast United States which could hit some portion of the coast"--is not unlike an earthquake prediction in that it contains scientific information about the state of nature. A hurricane warning--"the hurricane will hit the Miami coast within five hours and residents should seek high shelter"--is not unlike an earthquake warning in that it contains prescriptive statements for behavior based on interpretations of scientific information. One of the major differences between predictions and warnings for earthquakes and those for other natural hazards is that threat information can be available for a longer time, perhaps by months or years. Human response to the information in an earthquake prediction or warning has the time to be quantitatively and qualitatively different from response to other natural hazard predictions and warnings.

An Integrated Prediction-Warning System

Findings from the limited investigations of public response to earthquake warnings indicate that, despite the absence of much experience with earthquake warnings, officials can be guided by experience with, and studies of, warnings for other natural hazards.

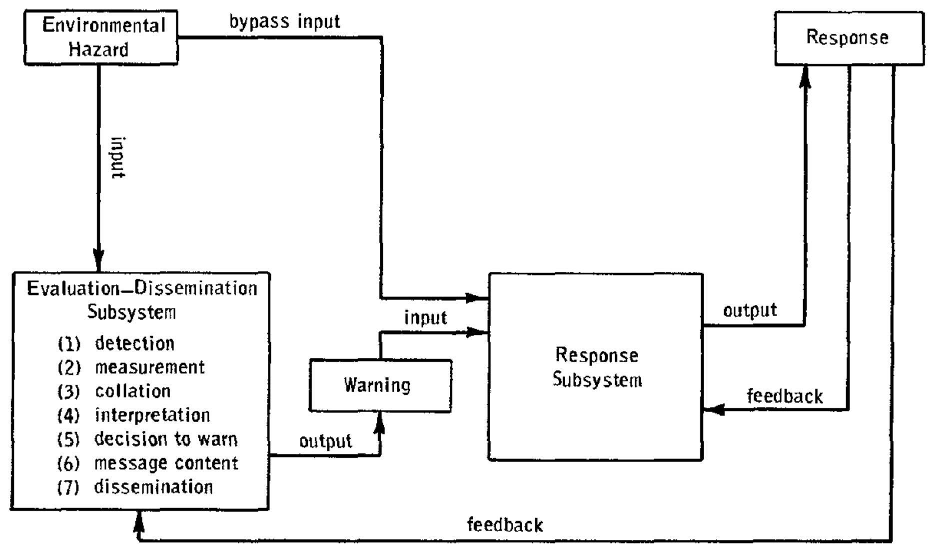
The aim of a prediction-warning system is to alert as many people as possible to the likelihood and consequences of an impending disaster, and to tell them what protective actions to perform. Warning system effectiveness, therefore, is measured by the extent of actions taken which result in reduced casualties and losses, and in increased emergency preparedness.

An integrated warning system performs three basic functions, as illustrated in Figure IV-2. Evaluation is the estimation of threat from a hazard to people in an area-at-risk. The processes involved in evaluation are detection, measurement, collation, and interpretation of available physical information about the threat posed by the impending hazard. Dissemination of a warning message to people in danger involves a decision about whether or not the evaluated threat warrants alerting the public to the possible danger, and telling them about it and what protective actions to take. Response, the third function of a warning system, is the taking of protective actions by the people who receive the warnings. People's actions, however, are preceded by their interpretations of warnings. These interpretations are directed by many social and psychological factors. To date, the response function has received least attention in designing and implementing hazard warnings of any type.

Warning system effectiveness is predicated on adequate linkages

FIGURE IV-2

AN INTEGRATED WARNING SYSTEM



between the three basic system functions. Evaluations and subsequent predictions are typically conveyed to emergency groups in the area to be affected by a formalized hazard-related organization. The groups are charged with alerting the endangered public and suggesting appropriate actions.

The dissemination-response link is vital, yet the dissemination of adequate warnings to endangered publics has been shown to be weak in warning systems as they are currently structured.

The Dissemination Function: Giving Information

Adaptive response by people to warnings can be influenced by the characteristics of a warning and a warning system.

Credibility

An important concept in explaining human response to hazard predictions and warnings is warning credibility. In order to identify factors which affect the perception of credibility for an earthquake prediction, we talked with 35 officials of organizations selected in a purposive sample of different organizational types.

These persons were asked to rank the relevance of various dimensions of a prediction in order of importance to their belief in the prediction: (1) reputation of the person or group making the prediction; (2) length of lead time, the amount of time between the prediction being made and the possible earthquake; (3) the magnitude of the predicted earthquake; (4) how specific the prediction was about the date when the earthquake was to occur; (5) how certain the people making the prediction were about whether the earthquake would actually occur; (6) how specific the prediction was as to where the earthquake would happen; (7) how much agreement there was among scientists about the prediction; and (8) observable actions being taken by government organizations behaving as if they believed the prediction. Respondents were asked to rank these elements with others they thought would be important to their believing the prediction.

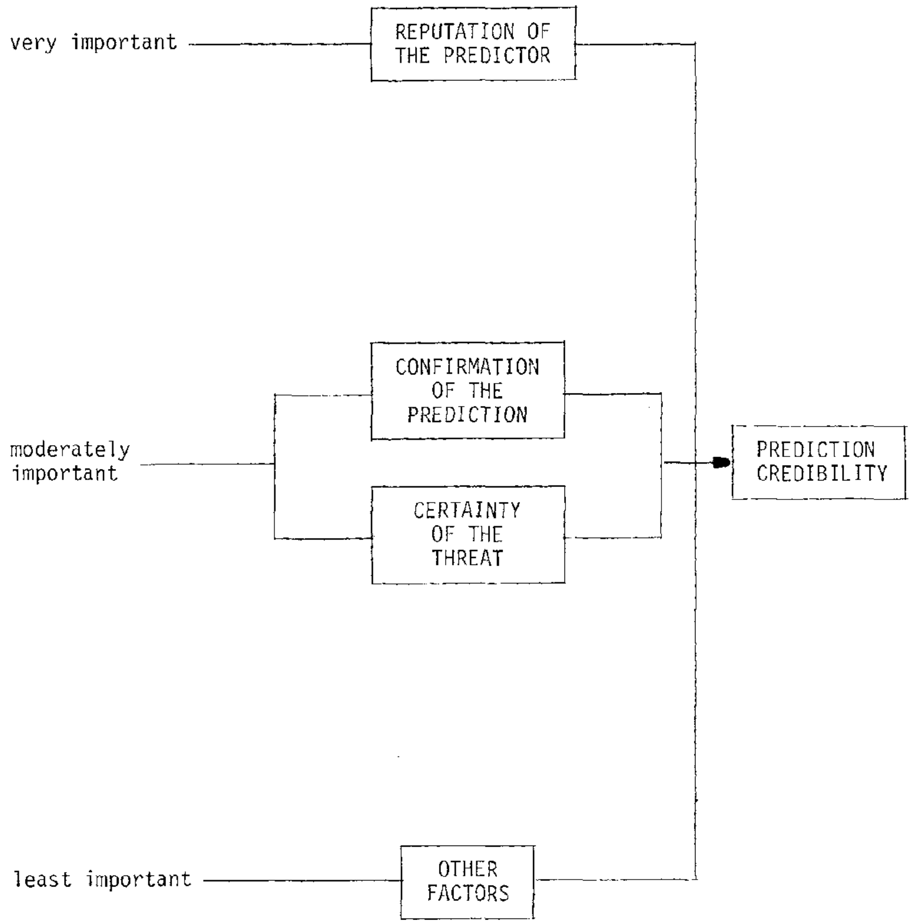
Our findings match those of previous warning response research and literature in identifying three important elements (see Figure IV-3) which will influence public perception of earthquake prediction credibility: (1) the reputation of the person or organization making the prediction; (2) confirmation of the information given in the prediction from other sources; and (3) certainty of the threat, or how sure the predictor is that the earthquake will occur (Mileti, Sorensen and Hutton, 1979).

The professional reputation (cf. Turner, *et al.*, 1979, pp. 135-150) of the person(s) or organization(s) making the prediction, the validation of the prediction by scientific peers, and the historical record of the science of predicting earthquakes bear on the reputation of the predictor. The public gives more credibility, and has a greater propensity to respond, to predictions based in scientific evidence. Furthermore, the greater the scientific reputation of the persons issuing and validating the prediction, the more credibility will be granted the prediction by the public. The record of earthquake prediction successes and failures will also be an important part of public evaluation of credibility.

There is a general human tendency in the face of adversity to seek evidence in support of maintaining the status quo; some people try hard not to believe information that a disaster is on its way. People will not want to decide to make changes in their lives in response to an earthquake prediction, so they will use all available information to find reasons not to take actions. Vague or conflicting information in the news about the prediction or about appropriate actions will impede public perception of prediction credibility. Confirmation will be a problem

FIGURE IV-3

RESPONDENT RANKING OF EARTHQUAKE PREDICTION CREDIBILITY DIMENSIONS



for early earthquake predictions because parameters of an earthquake prediction, such as the time of the event, are very likely to change over the duration of the prediction. The more changes in prediction parameters and the more debate about what the parameters really are, the fewer adaptive responses can be expected.

Also important to belief is how certain the predictor is that the earthquake will happen, and how specific the prediction is about when and where the event will happen. The higher the probability of occurrence, the more credible the prediction will be to the public. The relationship between intensity of the threat (how large or potentially damaging the earthquake) and prediction credibility is currently difficult to define, especially since the relationship of precursor data to earthquake magnitude is imprecise and may vary by as much as ±1 Richter magnitude during the course of the warning period.

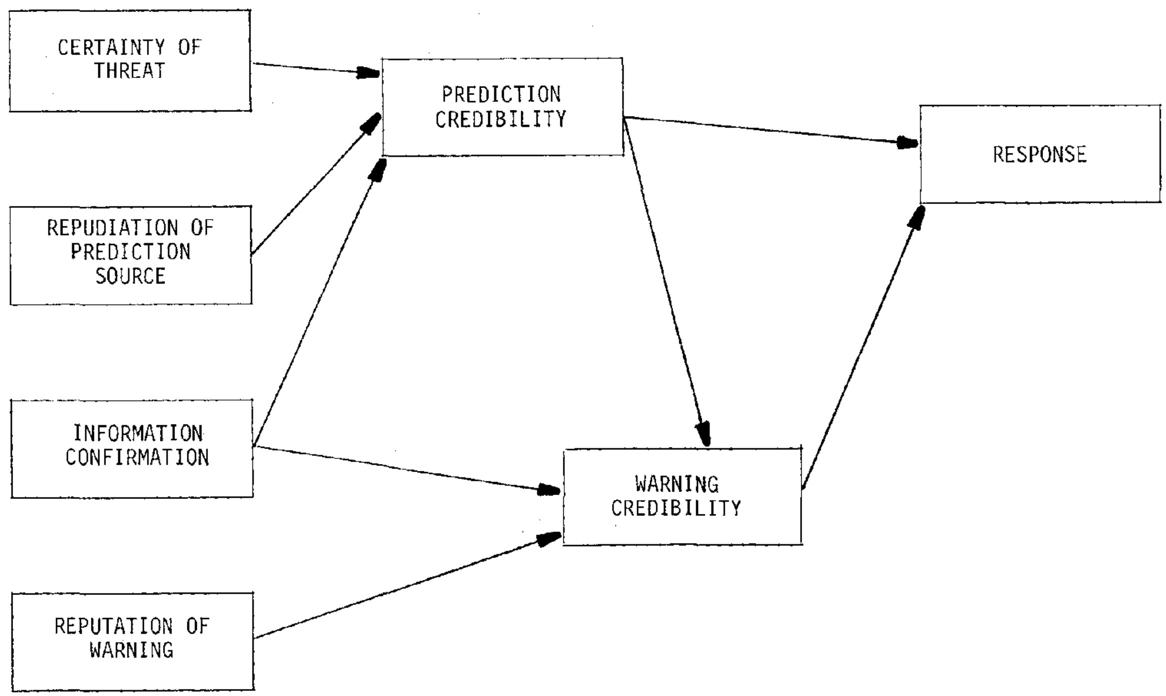
In addition to its influence on prediction response, prediction credibility will also have a major impact on whether or not a warning will be issued. It is inconceivable that an earthquake warning would be issued by government officials in the absence of high levels of credibility among scientists. Figure IV-4 illustrates the relationships between determinants of perceived prediction and warning credibility.

Equity

In the United States, current policies are that official predictions will be issued mainly by scientists (who may also be federal officials), and that warnings will be issued by officials of state and/or local governments. If individuals perceive that the warning originates from a reputable source, they are more likely to take adaptive responses. An important question for warning system design is whether perceptions of the reputation of the warning source will vary systematically for different kinds of citizens.

FIGURE IV-4

FACTORS LIKELY TO DETERMINE
PREDICTION AND WARNING CREDIBILITY



In our study, we questioned 243 families about their perceptions of credible information sources. The data were analyzed to determine if preferred sources differed along measures of socioeconomic status. Results were compared to the existing structure of earthquake information dissemination to determine if defacto inequities exist.

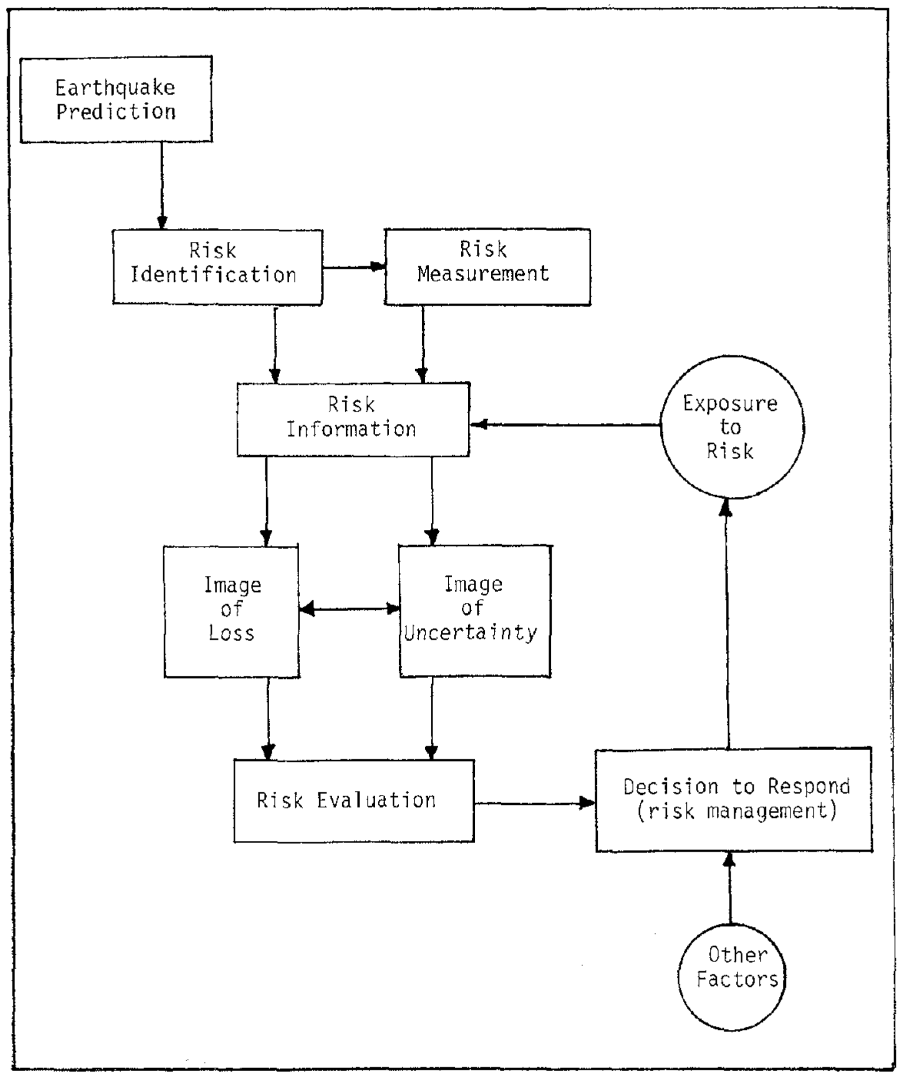
Local officials, including police and fire personnel, were named by over a third of the respondents, and private organizations like the Red Cross were named by about a quarter of the respondents. These data were then analyzed with respect to the socioeconomic status of the respondent and preferred warning source. Generally, persons of high and low socioeconomic status differed in their perceptions of preferred warning sources. Higher status citizens prefer government sources, while persons of lower socioeconomic status preferred information from the Red Cross. When these results were compared to the existing structure for the dissemination of earthquake warnings in the United States, it appeared that there is inequity inherent in the current warning system. We infer from the analysis that high status groups will be more apt to respond adaptively to earthquake warnings than persons of lower social status because there is no current plan to incorporate private organizations like the Red Cross into the earthquake prediction warning system.

The Dissemination-Response Link: Interpreting Information

It is useful to view earthquake prediction in a risk assessment framework (cf. Kates, 1978). Persons face a variety of risks in daily life, and earthquake is one risk for some of them. People constantly identify risks, attach a measurement to the risks, and evaluate the acceptability of that risk, though whether this is articulated in these terms by individuals is of little importance. An earthquake prediction, alone or with a warning, is new risk information (see Figure IV-5).

FIGURE IV-5

THE RISK ASSESSMENT PROCESS



Stage one, risk identification, suggests that people must be aware of a risk before they will take action. Stage two, measurement, is the way people attach likelihood to the risk. This may be in quantitative terms, such as a Richter magnitude or probability, or in more qualitative terms, such as "likely" or "a chance." The assessment process may end at this stage if a value cannot be attached to the risk.

Stage three, risk evaluation, is a more difficult process to identify and understand. It covers how individuals or organizations utilize risk measurements in making a decision. This can be a highly rigorous and complex process, as in the case of applying decision analysis to evaluate the safety of a skyscraper, or a very simple one, as in the case of a homeowner deciding to purchase earthquake insurance.

When an earthquake prediction is made, there will be a great increase in risk assessment activity. More persons will be more aware of the risk, more measurements will be made, and evaluations will be deliberately or subconsciously made. It is important that individuals, businesses, and government agencies become good risk assessors because good assessments will lead to more optimal societal response. The information needed to guide constructive response will not be the same for everyone; differences will exist between people in knowledge about earthquake risks and ability to understand risk concepts and information. In this context, current and future information programs on earthquake risk will improve society's capabilities to assess the risks of the hazard, as well as improve response to the predicted event.

Identifying Risks

Earthquake risk includes primary hazards such as damage to property and fatalities from shaking and fault movement, and secondary hazards such as landslides, fire, tsunami or avalanche. Other risks are less obvious, such as social disruption or psychological damage.

Scientists can, within practical limits, identify these risks, but for laypersons, this may be a complex and difficult task. A warning from a credible prediction should be full of information which will enable everyone to identify the complete range of earthquake risk faced in any given location or situation.

Measuring the Risk

Earthquake risks can be stated in quantitative terms. For a prediction, it is the parameters of lead time, time window, location, magnitude and probability. For a seismic event, it can be maximum ground shaking, expected intensity, liquefaction potential, or other measures. However, it is unlikely that all the risks will be measured, and many will be cast in qualitative rather than quantitative terms. For this reason, it is important to determine what shapes cognition of a risk by both people and organizations. The components of risk perceptions are uncertainty and image of damage.

Levels of uncertainty. It is likely, because of the nature of prediction technology, that the first few predictions will have some uncertainties. In addition, even if the parameters are stated with clarity, lack of prediction experience may generate suspicion and bewilderment. Four elements of uncertainty are lead time, time window, location, and probability.

The lead time of a prediction may range from a day to perhaps a decade. As the lead time increases, the level of uncertainty rises, but, paradoxically, as lead time increases, the ability to take a broader range of adaptive responses may also rise. Shorter lead times may, however, increase the tendency to take action. Our research showed that many individuals prefer a short lead time, although it may well serve the collective good to have longer lead times in which to take precautionary measures.

The specificity with which scientists can predict the date of an earthquake will also influence the level of uncertainty. Time windows may range from a day to a year. A rough correlation exists between lead time and time window--the greater the lead time, the larger the time window. The Chinese experience implies that small time windows may accompany short lead times. Uncertainty will increase as time windows broaden, and this can affect the propriety of certain measures to mitigate potential losses.

Uncertainty will be increased by a vague delineation of the area in which the predicted earthquake could occur. Scientists cannot yet specify how large or small the target. If an earthquake is predicted for a large area, the uncertainty will have a negative effect on determining vulnerability. This will hinder good risk assessments and, more importantly, alter the image of loss.

Finally, the lower the probability of the event, the greater the uncertainty. People will translate any numerical probability into a variety of terms meaningful to themselves. A large body of psychological literature suggests that people are inconsistent in their use and interpretation of quantitative information. This inconsistency emphasizes a need for facilitating public understanding about what is meant by the probability attached to a prediction, particularly if it is a low one.

Image of damage. People's perceptions of damage or losses from the predicted earthquake will also influence response. Objectively, expected loss can be measured by exposure to risk, but image of damage will also be influenced by maps of projected damage, vulnerability assessments, past experiences, and other related knowledge and information.

Critical to determining exposure to risk are the physical characteristics of location and landscape, including soils, slope, surface geology and other natural influences. In addition, human interventions, such as reservoirs, or slope denudation may have influences on the environmental character of risk. Locational choices and architectural practices also determine vulnerability to loss.

To delineate accurately the role such factors play in determining overall vulnerability to a predicted earthquake is time-consuming and expensive. Such determination, however, does not necessarily need to be tied to a prediction; it can be initiated at any time and updated periodically. As delineations of earthquake risk become more prevalent, the ability to determine vulnerability to a predicted event and respond appropriately will increase.

The monetary value of buildings and possessions is also related to the image of loss. The level of resources individuals and organizations have committed in a target area may have a large effect on their response to new risk. Human use is more easily measured than environmental factors. Current monitoring and inventory of property-at-risk would enable easier risk assessments if a prediction were issued.

Magnitude, maps of damage levels, assessment of vulnerability, media information, and past experiences also shape image of damage. In scientific terms, there is a crude relationship between the magnitude of an earthquake and damage levels. The relationship is not, however, linear or constant. It is unlikely that decision makers will adjust their images of damage to small differences in the predicted magnitude since it is more likely that individuals have a threshold at which a predicted magnitude drastically increases or decreases their image of damage. It may be important to help decision makers distinguish between Richter magnitude and Mercalli intensity since many people confuse these two scales. The latter may be more useful in projecting more accurate images of potential damage.

Following a prediction, maps of potential damage will be published. These maps could drastically vary in complexity from a simple map depicting areas which are forecast to experience heavy damage, to computer-generated maps showing isoseismic intensity patterns. Maps could also vary on the basis of different underlying assumptions and definitions. What criteria would be used to determine a qualitative category such as "heavy" damages? What assumptions are made about the location and depth of the earthquake epicenter?

Publication of different maps would create confusion and uncertainty within the public. Our research shows that persons who believe that they will experience heavy damage also have a greater belief that a predicted earthquake will occur. In addition, images of higher damage produced by a map can stimulate a search for more information on vulnerability. Therefore, it is vital that maps contain the most accurate available information. Faulty maps could stimulate too much or too little adaptive behavior.

Some decision makers will choose to obtain more detailed or personalized information on risk. One of the more common requests may be for assessing the vulnerability of houses, and commercial or industrial buildings. An engineering assessment of vulnerability will be easy to obtain if one has the monetary resources, but detailed study will be expensive. Given that the parameters of the prediction may well be imprecise, and that the causes of damage to a structure are numerous and complex, such measurements may not provide as sound a basis for decisions as the risk assessor might desire.

Information Dissemination

We now attempt to ascertain how media sources, including television, radio and periodicals, will handle the story of an earthquake prediction. Derived primarily from interviews with over a dozen major and some minor media organizations, Table IV-1 provides an overview of the mechanism of information dissemination.

TABLE IV-1

INFORMATION DISSEMINATION

CONTENT	
Risk Information	General Information
Magnitude Damage Maps Possible Impact (Economic) Techniques of Reducing Risks	Credentials of Predictor EQP-State of the Art History of Prediction Scientific Opinions Reaction of Public Official's Statements What to do Human Behavior

CHANNELS	
Public	Private
Newspaper T.V. Radio Periodicals Special Pamphlets Telephone Hotlines Mass-mailings	Inter-personal Communication Information Services Private Newsletters Consulting Services

In an attempt to determine if one information channel, a major newspaper, was consistent with what large news media organizations said they would cover during our interviews, we compared actual newspaper coverage of Whitcomb's prediction to perceived interview media coverage. Table IV-2 summarizes the results of this comparison, and Figure IV-6 presents the intensity of coverage given to the prediction. Coverage of the actual prediction was very similar to that imagined. Two types of coverage which did not receive attention were statements by public service groups, such as the Red Cross, and statements about potential damage.

TABLE IV-2

MEDIA COVERAGE OF AN EARTHQUAKE PREDICTION

Prediction — One Week →

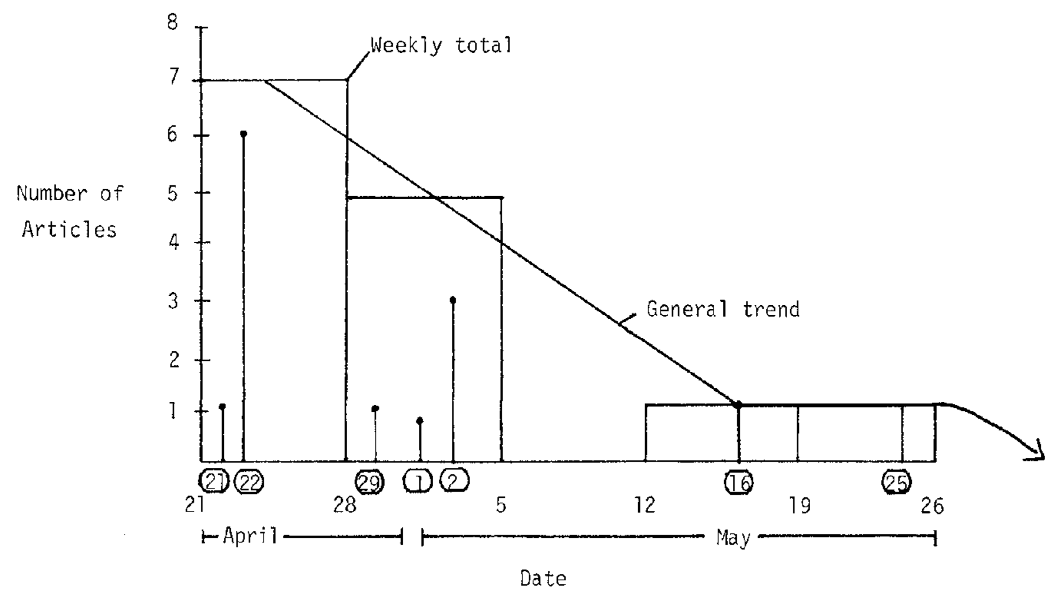
Scenario A Media Coverage	Whitcomb "Prediction" Media Coverage*
Parameters of the Prediction	April 21st -Location -Magnitude -Time Window April 22nd -Editorial
Credentials of the Predictor	April 29th -Article on James Whitcomb -Interview with Whitcomb
Scientific Feasibility	April 21st -Description of theory and procedure May 2nd -Article by Whitcomb
Scientific Consensus	May 1st -Coverage of California EQP Evaluation Council meeting
Statements of Public Officials	April 22nd -LA County Disaster Services May 1st -State OES May 2nd -LA City Schools
Statements of Public Service Organizations (e.g., Red Cross)	None
Potential Damages from the Earthquake	None
Economic Impact of the Prediction	April 22nd -Real Estate Value -Insurance May 2nd -General Impacts

**Los Angeles Times*, April 21-May 31, 1976

FIGURE IV-6

INTENSITY OF NEWSPAPER COVERAGE

LOS ANGELES PREDICTION



Discussion earlier in this chapter pointed out that these are critical ones. This illustrates a need for sound information management in an earthquake prediction.

Information dissemination will expand if the seriousness of the situation warrants that. Radio stations indicated that they would consider a regular program to update information. Telephone hot lines could be set up as part of police and fire department duties. Utility companies thought they would attempt to reach customers through regular billings, and other groups may also engage in the special mass-mailing of information. Finally, it is difficult to assess the role interpersonal communication will play. It seems reasonable to assume that a prediction will be a popular topic for lunch room and other informal discussions. Kunreuther, *et al.* (1978) have documented that informal communication plays an important role in the decision to buy flood hazard insurance.

Information Utilization

Everyone will not have equal amounts of information, nor does everyone have the same capacities for understanding risk information.

Studies have been conducted on how persons perceive, interpret, and utilize probabilistic information in making decisions (Lichtenstein, *et al.*, 1978). The implications for hazard management are summarized in an article by Slovic, Kunreuther, and White (1974). Some general conclusions from this research are these: (1) people will have difficulty understanding the meaning of probability or confidence level attached to a prediction; (2) people will have difficulty estimating the consequences of the predicted event; (3) people will not be aware of all the actions they could employ to mitigate the possible consequences; (4) people will have difficulties in deciding on the proper behavior; and (5) because people have different goals, their behavior may differ from what the experts perceive as being advantageous or optimal.

Earlier in this study we reported that in Wilmington, North Carolina, the level and accuracy of information people had about the prediction increased with level of socioeconomic class. People who were non-white had a much less accurate knowledge of the prediction, where accuracy was determined by holding correct information about the predicted data and magnitude. As a result, people of higher socioeconomic status were more likely to take precautionary measures.

Prior studies and our field work suggest that people cope with risk information in several ways: avoidance, rationalization, comparisons and analysis. Some people will decide to avoid the risks of a potential earthquake. They will have a low tolerance for risk and have images of great damage potential. Our field work shows that the proportion of the general public which will employ this strategy is small, and will likely range between 0 and 10%, depending on the situation. A second way people may choose to avoid risk is to avoid understanding the prediction.

Another segment of the general population may respond to the risk by rationalization. There is a variety of ways to do this, but one will be the denial of the scientific ability to predict earthquakes. Another example of rationalization is to manipulate risk cognitions: "An earthquake of that magnitude won't do any damage to me" was reported by some 30% of our family respondents.

Some people will, in the course of making decisions, compare the risks of the predicted earthquake with other earthquake events or other risks. No data exist for estimating the likely numbers.

With varying degrees of sophistication, people and organizations will utilize analytical frameworks to evaluate risk. People may compare the costs of taking certain actions with general levels of perceived risks, or with the benefits of reducing risks, as in the case of reinforcing a chimney or staying home from work. Some government agencies may employ simulation models to evaluate risks, and engineering firms will do likewise. The general public will employ some cruder techniques of risk analysis.

The overriding question for all is what level of risk is acceptable. This question is closely linked with risk cognitions. If, following a prediction, no significant changes in behavior or earthquake risk cognition ensued, we could judge that the predicted risks did not exceed what society deemed acceptable. Yet such a lack in cognitions may not be desirable.

One goal of public policy is to achieve a prediction response which is commensurate with the risks, especially since decisions can be made which represent over-responses or under-responses. For example, a prediction of a 6.0 Richter magnitude earthquake should not stimulate massive purchases of insurance if the cost of insurance were pitted against likely damages, or wholesale migrations from the area. On the other hand, it should lead to some appropriate forms of response.

As exposure to damages increases, response should grow in a proportionate manner. If risks are overestimated, too much adjustment could occur and result in an inefficient allocation of resources. Overadjustment may also be a stimulating force to undesirable prediction-induced impacts such as economic slowdowns or real estate slumps.

Conversely, risk rationalization may lead to an underestimation of risks, resulting in too little adaptive response, vulnerability reduction, and preparedness. As decision makers at all levels of society become better and more analytical risk assessors, predictions and earthquakes will result in less damage and social disruption. While the problems and constraints to achieving better risk assessment capabilities are numerous, it still remains as a desirable societal goal.

Responses

In this section we present our conclusions on how and why people and decision makers will respond to the information contained in an earthquake prediction.

Decision Choices and Prediction Response

Our research into the probable decisions and behaviors of people and public and private decision makers indicates that there are three response strategies. These strategies subsume all anticipated prediction responses given to us by citizens and decision makers in both open-ended and structured interviews. These are the 1) relocation, 2) reduction, and 3) reallocation of activities, people and resources. While these categories are mutually exclusive, they are not substitutes for each other; any one individual could take actions that fall into one, two or all three of these categories. Table IV-3 illustrates the potential use of these three strategies to achieve the two goals of earthquake prediction.

TABLE IV-3

THE RESPONSE STRATEGIES AND GOALS OF EARTHQUAKE PREDICTION

		RESPONSE STRATEGY		
		Reallocation	Reduction	Relocation
GOAL	Increase Vulnerability	• people • resources • activities	• people • resources • activities	• people • resources • activities
	Increase Preparedness	• people • resources • activities	not applicable	• people • resources • activities

Relocation. The act of relocating work, activities, people, and/or resources out of the area-at-risk, or from the focal point to the periphery of the area-at-risk, can serve to reduce vulnerability or increase emergency preparedness. Relocation also includes a range of lesser but more prevalent acts such as taking pictures off the wall or packing away favorite glassware.

For government decision makers, relocation can include having the city hall locate to temporary offices in an area of lesser risk; for corporate decision makers, it can be moving records to an area of lesser risk or having employees work at a branch office in an area of lesser risk; for family decision makers, it can be going to live with friends or relatives or moving valuables to an area of lesser risk. Such temporary relocation of activities, people and resources to an area of lesser risk would protect the ongoing functional operations of a firm or a branch of government from the disruption the earthquake could cause, and maintain family safety, with expeditious effectiveness but with varying levels of cost and disruption.

Government relocation to increase emergency preparedness will be large. National disaster agencies will move close to the risk area to enhance quick service delivery. Local government will move to lesser risk areas, close by, to ensure service delivery. Corporate decision makers will relocate financial reserves to enhance quick restoration of operations. Family decision makers, however, will seldom employ this strategy to enhance emergency preparedness. Perhaps the most certain and significant bonus provided by an earthquake prediction is the opportunity for emergency response operations to relocate in or out of the risk area in anticipation of the event.

The study asked organizational decision makers about the relocation of work activities, both temporarily and permanently, the reassignment of employees to geographical areas out of the area-at-risk, and the removal of resources such as records and machinery to safer areas. Families were asked about an anticipated temporary and permanent change in residence, work transfer, job change, moving possessions and separation of family. Our study of response to the non-scientific prediction in North Carolina also questioned families along these same lines, as did both hypothetical and actual prediction response questions for organizations in Japan. Organizational officials were asked to speculate on the location of new or additional emergency operations, increased staff size, increased emergency supplies, inventory and financial resources. Family hypothetical response was similarly queried, as was Japanese organizational response to both actual and hypothetical predictions.

Reduction. Reduction in activities, people or resources refers to decisions such as temporarily discontinuing the manufacture of vulnerable goods in local plants, slowing down production, reducing the labor force, reducing consumption of natural gas, and other activities which would otherwise increase the potential for loss. We have no evidence to suggest that reduction is a strategy which in any way affects emergency preparedness; it seems only to alter vulnerability. Such decisions for government decision makers might be the temporary suspension of work in an area of high risk; for corporate decision makers, they might be a slowdown in production or inventory maintained in a high risk area; and for family decision makers, they may be turning off the gas or postponing large purchases.

Such activities, which are more likely if decision makers do not make relocation decisions to reduce risk to activities, people and resources, also promise to lessen what is lost when the earthquake occurs. This strategy will be used to a greater extent in an earthquake prediction than the relocation strategy because it is easier and less expensive.

Response was assessed for organizations with questions on anticipated decisions to decrease staff size, cut back on some work activities, and decrease inventories. Families were questioned on items such as the cancellation of large purchases, reduction in social interaction and reduced savings. Hypothetical and actual prediction response by organizations in Japan were also assessed along these same lines.

Reallocation. The reallocation of priorities can be used both to reduce vulnerability and increase emergency preparedness. Reallocation decisions for government decision makers would include shifting budgets to cancel scheduled expenditures to free monies for risk-mitigation actions; for corporate decision makers, they include rearranging markets or contracts; and for family decision makers, they involve altering scheduled or normative activities to, for example, keep the family unit together more frequently.

To increase emergency preparedness, families will stockpile emergency supplies, disaster response agencies will establish arrangements to share facilities and equipment with others, and corporations will reassign some employees the task of preparing and updating emergency plans.

The hypothetical response of organizations was assessed with questions on the reallocation of finances, mutual aid pacts with other organizations, and arrangements to share resources, facilities, supplies, personnel and equipment for response to the earthquake. They were also asked about the rearrangement of financial priorities, the reallocation of work activities, tasks and priorities, and changes in budgeting. Family hypothetical response was assessed in reference to changes in savings patterns, spending patterns, consumption, social interaction and utility usage. Japanese organizational response to both hypothetical and actual prediction response was assessed similarly.

Explanations of Response

Many of these decisions for response will be made only after the prediction is enhanced by an official warning; other decisions will be made on the basis of the prediction alone. The more credible the prediction, the more likely it is that response decisions will follow from the prediction. This section discusses what our data suggest about *why* decision makers and people will make different decisions and responses in the earthquake prediction-warning setting.

Six elements were suggested by our data as important in determining actions that will be taken and not taken to reduce vulnerability and increase emergency preparedness after a prediction-warning: (1) image of damage, (2) exposure to risk (insurance), (3) exposure to risk (others), (4) access to information, (5) commitment to the target area, and (6) resources. These were the study's independent variables; they are partial explanations for various responses (the five dependent variables): relocation, reduction, reallocation.

Image of damage. What people and decision makers think will happen if the predicted earthquake occurs will greatly influence their deciding what should and will be done in response to a prediction-warning. Our data lead us to conclude (see Table IV-4) that the more damage anticipated, the more likely people and decision makers will decide to reduce vulnerability and increase emergency preparedness.

Image of damage was controlled for in eliciting the response of families by showing respondents a hypothetical damage map. The map was divided into geographical areas of high, moderate, and low or no damage. Respondents were differentially and randomly assigned to a "damage area" before interviewing began about prediction response. Consistently, for anticipated response associated with relocation, reduction and reallocation strategies for both vulnerability reduction and increases in

TABLE IV-4

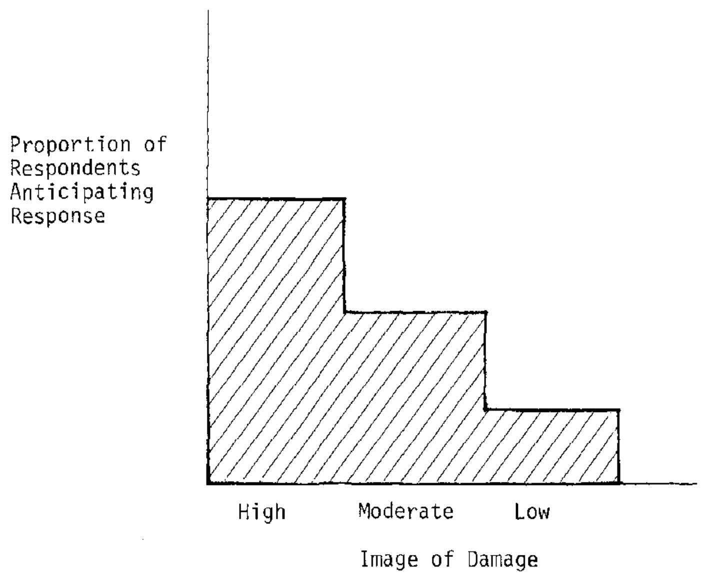
THE EFFECTS OF IMAGE OF DAMAGE
ON EARTHQUAKE PREDICTION DECISIONS*

DECISIONS ↓	FAMILY	CORPORATIONS	LOCAL BUSINESS	STATE-FEDERAL AGENCIES - SERVICES	LOCAL GOVERNMENT AGENCIES - SERVICES
RELOCATION TO REDUCE VULNERABILITY	+	+	+	+	+
REDUCTION TO REDUCE VULNERABILITY	+	+	+	+	+
REALLOCATION TO REDUCE VULNERABILITY	N/D	+	+	+	+
RELOCATION TO INCREASE EMERGENCY PREPAREDNESS	N/D	+	+	+	+
REALLOCATION TO INCREASE EMERGENCY PREPAREDNESS	+	+	+	+	+

*N/D = no data available; + = positive effect emergency preparedness, the higher the image of damage people were asked to assume, the more likely was anticipated response (see Figure IV-7). Even for questions where only 10% of the total sample thought they would take action, of that 10%, those with a high image of damage were more certain they would take action.

FIGURE IV-7

ILLUSTRATION OF EFFECT OF IMAGE OF
DAMAGE ON ANTICIPATED FAMILY RESPONSE



The same relationship between image of damage and anticipated response was revealed with organizations--local, state and federal agencies, as well as local, regional and national corporations. Organizational respondents were asked about anticipated response to two different predictions, one for a 6.3 and another for a 7.3 Richter magnitude earthquake. Again, and with little exception, anticipated response was approximately 10-20% more probable to the larger magnitude earthquake than to the earthquake of lesser magnitude.

At the same time, organizations with actual earthquake and/or other natural disaster experience anticipated more responses, regardless of the size of the predicted earthquake. It was more difficult for social units with actual disaster experience to underestimate risk from the hypothetically predicted earthquake. Organizations with experience could have higher images of damage than organizations without such experience. Such experience, for example, correlated at the .05 level of significance with the anticipated responses of temporary relocation ($r = .27$), the reassignment of some employees to prediction or earthquake-related tasks ($r = .34$), cutting back on activities in the area at risk ($r = .24$), altering operations because of the prediction ($r = .37$), altering staff size because of the prediction ($r = .32$), and arranging interorganizational mutual help agreements ($r = .42$). Moreover, these effects were not diminished when controlling for other independent variables that were correlated to these behaviors through the use of standardized regression coefficients.

In short, evidence is strong that image of damage is positively and directly related to most earthquake prediction responses for both families and organizations. Unfortunately, however, some people and decision makers will overestimate damage, many will hold accurate images of damage, and others will underestimate damage in a prediction-warning setting.

Over-reaction to a prediction-warning will incur unnecessary societal costs. Taking greater actions than are appropriate to the actual risk has the potential to increase negative secondary effects (a failing economy). Such negative effects are discussed in a subsequent section of this chapter. Under-reaction to a prediction-warning could constrain achieving the goals of prediction technology--vulnerability reduction and increases in emergency preparedness--and a greater total cost would ultimately be paid. Appropriate response to an earthquake prediction-warning will only proceed on the basis of widely held *accurate* images of damage.

Inaccurate images of damage will result from several causes, among the most prominent of which is one repeatedly documented in the literature on natural hazards: people deny or diminish the threat of hazards to themselves and their possessions. A pioneering paper by Burton and Kates (1964) illustrated that residents of hazardous areas frequently deny risks by eliminating their recurrence--"floods can't happen here" or "lightning doesn't strike twice"--or by denying their existence. There is no basis on which to conclude that this will not be the case with a predicted earthquake. Denial of personal threat will cause some decision makers to underestimate damages. People also tend to assume that their last hazard experience will be similar to subsequent ones. This will cause some people and decision makers to overestimate damage and others to underestimate it.

Our interviews with national, regional and local media showed that a prediction-warning will also cause a surge of well-intentioned and reputable media attention to the subject of earthquakes and earthquake damage. In the public interest, pictures and stories of damage in Managua and San Fernando, for example, will be shown. Such histories may alter damage perceptions for the predicted earthquake even though building designs, magnitudes, and intensities of historical quakes may be quite different from the predicted quake. Numerous different damage maps will be made public in a prediction setting. Images of damage could be changed every time another map is seen. Decision makers will probably be able to choose the map which describes the extent of damage to themselves they would most prefer (none, some, total). Without a concerted effort to determine systematically how images of damage will be presented, people and decision makers will be unnecessarily confused.

Exposure to risk (insurance). Our evidence confirms that holding earthquake insurance--and thereby having reduced risk to earthquake loss--

may constrain decisions to reduce vulnerability for some kinds of decision makers, and have no effect on vulnerability reduction decisions for others (see Table IV-5). Corporations and businesses which are insured against earthquake loss are not apt to take actions or make decisions to further reduce their vulnerability to the earthquake hazard because of a prediction-warning. For example, the effect of holding insurance was negatively correlated to anticipated responses for temporary relocation ($r = -.30$), moving records ($r = -.39$), curtailing activities in the area-at-risk ($r = -.43$), and shifting internal priorities ($r = -.43$). At the same time, it was positively correlated with some anticipated responses which would actually increase vulnerability, for example, increasing inventory ($r = .32$), and increasing physical resources ($r = .77$). Holding insurance had no effect on altering the anticipated response of governmental organizations and families to reduce vulnerability; it was not significantly correlated either negatively or positively.

Our analyses (see Table IV-5) also suggest that possessing earthquake insurance has no effect on vulnerability reduction or emergency preparedness decisions for citizens (families) or state and federal agencies, bureaucracies and organizations. Having insurance served to enhance decisions to take emergency preparedness measures for large corporations, local businesses, and local government agencies and service organizations.

By and large, holding earthquake insurance is the result of awareness and recognition of the hazard, and this same hazard awareness, in a prediction-warning setting, enhances decisions to upgrade emergency preparedness by most decision makers. However, earthquake insurance held by businesses (both large and small) appears to inhibit further decisions to reduce the vulnerability of physical properties. It may be that it is not practical if insurance exists to cover the costs of any damage.

TABLE IV-5

THE EFFECTS OF EXPOSURE TO RISK (INSURANCE)
ON EARTHQUAKE PREDICTION DECISIONS*

DECISIONS ↓	FAMILY	CORPORATIONS	LOCAL BUSINESS	STATE-FEDERAL AGENCIES - SERVICES	LOCAL GOVERNMENT AGENCIES - SERVICES
RELOCATION TO REDUCE VULNERABILITY	0	-	-	0	0
REDUCTION TO REDUCE VULNERABILITY	0	-	-	0	0
REALLOCATION TO REDUCE VULNERABILITY	N/D	-	-	0	0
RELOCATION TO INCREASE EMERGENCY PREPAREDNESS	N/D	+	+	0	+
REALLOCATION TO INCREASE EMERGENCY PREPAREDNESS	0	+	+	0	+

*N/D = no data available; + = positive effect; - = negative effect; and 0 = no effect

Exposure to risk (other elements). There are other elements of risk, for instance, in-place adjustments to the earthquake hazard--building design and site selection--as well as value of property and structure, proximity to the fault, and proximity of property to secondary earthquake hazards. The effects of these on vulnerability reduction and emergency preparedness decisions are presented in Table IV-6.

Vulnerability reduction and emergency preparedness decisions seem more likely to be made by all kinds of decision makers as exposure to risk increases. However, the greater the extent of already in-place earthquake adjustments, the lesser the risk, but the more likely decision makers are to reduce risk further. As was the case for earthquake insurance, for some kinds of decision makers, having adopted other earthquake adjustments while lessening risk is the result of awareness and recognition of the hazard, and this awareness, in the prediction-warning setting, enhances decisions to reduce vulnerability and increase emergency preparedness further. The larger the absolute risk to physical property, structure, and belongings, i.e., what one has to lose, the more likely are decisions to decrease vulnerability and increase emergency preparedness.

Associated with decisions to (1) relocate temporarily were assets at risk ($r = .55$), physical property at risk ($r = .43$), adjustments to secure movable belongings ($r = .36$), site selection taking earthquake hazard into account ($r = .29$), and structural adjustments ($r = .49$); (2) to curtail activities in the area at risk were use of earthquake hazard land use planning ($r = .34$), securing of belongings ($r = .36$), and assets at risk ($r = .45$); (3) to decrease staff size because of the preduction were property at risk ($r = .33$), and structural modifications ($r = .50$); (4) to decrease inventory were profits increasing in area at risk ($r = .53$), assets at risk ($r = .60$), and earthquake planning ($r = .59$);

TABLE IV-6

THE EFFECTS OF EXPOSURE TO RISK
(OTHER ADJUSTMENTS AND ECONOMIC AND PHYSICAL INDICATORS)
ON EARTHQUAKE PREDICTION DECISIONS*

DECISIONS	FAMILY	CORPORATIONS	LOCAL BUSINESS	STATE-FEDERAL AGENCIES - SERVICES	LOCAL GOVERNMENT AGENCIES - SERVICES
RELOCATION TO REDUCE VULNERABILITY	+	+	0	+	+
REDUCTION TO REDUCE VULNERABILITY	+	+	+	0	+
REALLOCATION TO REDUCE VULNERABILITY	N/D	+	0	+	+
RELOCATION TO INCREASE EMERGENCY PREPAREDNESS	N/D	+	+	+	+
REALLOCATION TO INCREASE EMERGENCY PREPAREDNESS	+	+	0	+	+

*N/D = no data available; + = positive effect; 0 = no effect

(5) to rearrange financial priorities were assets at risk ($r = .47$), use of structural modifications ($r = .38$), geographical location selected while considering the earthquake hazard ($r = .46$), and structural modification ($r = .33$); (6) to alter activities in the area at risk were land use planning ($r = .32$), disaster planning ($r = .28$), and resources at risk ($r = .43$); (7) to alter inventory were property at risk ($r = .55$), assets at risk ($r = .57$), facilities at risk ($r = .58$), disaster planning ($r = .42$), and structural adjustments ($r = .42$); and (8) to arrange to share resources with others and establish mutual aid agreements, resources at risk ($r = .30$), disaster planning ($r = .41$), property at risk ($r = .51$), and facilities at risk ($r = .38$).

It seems sound to conclude that the greater the earthquake risk to an organizational decision maker, the more likely he or she is to respond to a prediction-warning by decreasing vulnerability (risk) as well as by increasing emergency preparedness. The same conclusion is applicable to families. Factors having a significant effect on many family prediction-warning responses were proximity to the fault, financial investments in the area at risk, and physical assets.

Persons without much to lose because of an earthquake may not do much because of a prediction. However, given the uncertainties in reference to actual damage in an earthquake, it would be desirable for all decision makers, even those with little apparently at risk, to engage in a sound scheme for emergency preparedness. Unfortunately, decision makers who conclude, perhaps falsely, that they are free from risk may dismiss the need to engage in emergency preparedness.

Access to information. Different social units and decision makers (corporate, government, family) have more or less access to information than do others during the normal routine of life. Some organizations, for example, have the resources to employ staff whose job it is to get, process and refine information of interest or concern to the organization. Others lack the need for such employees or the resources to hire them. Decision makers who have access to good information are more likely to reduce earthquake vulnerability and increase emergency preparedness. All types of decision makers are likely to increase emergency preparedness (see Table IV-7), and business organizations are likely also to make vulnerability reduction decisions.

This conclusion, limited by the data available to us to business and government organizations, is based on the relationships between information access factors for organizations (for example, budget expended on monitoring the environment, interorganizational autonomy, participation in associations, and interaction frequency with other organizational officials). For businesses, access to information was positively related to vulnerability reduction and increases in emergency preparedness response: (1) temporary evacuation with monitoring budget ($r = .54$), interorganizational autonomy ($r = -.29$), participation in associations ($r = .59$), interaction frequency with other organizational officials ($r = .47$); (2) reassignment of employees out of the area at risk with interorganizational autonomy ($r = -.34$); (3) moving records with monitoring ($r = .37$), interorganizational autonomy ($r = -.56$), interaction frequency with other organizational officials ($r = .53$); (4) curtailing activities in the area at risk with interorganizational autonomy ($r = -.50$), monitoring ($r = .56$), interaction with other organizational officials ($r = .33$); (5) decreasing inventory with interorganizational autonomy ($r = .38$); (6) rearranging organizational priorities with participation in associations ($r = .37$) and autonomy ($r = -.37$); (7) changing internal tasks with monitoring ($r = .37$) and autonomy ($r = -.30$); (8) increasing staff size to prepare for the earthquake with monitoring ($r = .42$), autonomy ($r = -.47$), participation in associations ($r = .33$), and interaction with other

TABLE IV-7

THE EFFECTS OF ACCESS TO INFORMATION ON EARTHQUAKE PREDICTION DECISIONS*

DECISIONS ↓	FAMILY	CORPORATIONS	LOCAL BUSINESS	STATE-FEDERAL AGENCIES - SERVICES	LOCAL GOVERNMENT AGENCIES - SERVICES
RELOCATION TO REDUCE VULNERABILITY	N/D	+	0	0	0
REDUCTION TO REDUCE VULNERABILITY	N/D	+	0	0	0
REALLOCATION TO REDUCE VULNERABILITY	N/D	+	0	0	0
RELOCATION TO INCREASE EMERGENCY PREPAREDNESS	N/D	+	+	+	+
REALLOCATION TO INCREASE EMERGENCY PREPAREDNESS	N/D	+	+	+	+

*N/D = No data available; + = positive effect; 0 = no effect organizational officials (r = .40); and (9) making arrangements to share facilities for the emergency with autonomy (r = -.50).

For business corporations, access to information is directly related to taking actions both to increase preparedness and decrease vulnerability because of a prediction. Findings were the same for local and federal governmental agencies and organizations, but only for emergency preparedness decisions; information access had no effect on altering vulnerability reduction decisions for these kinds of organizations.

Equity in access to information will be a troublesome concern in an earthquake prediction-warning setting. Public information campaigns and packages must be delivered and designed in such a way to maximize equity in access to this information. Packages must be made specific to the needs and capabilities of each particular class of user.

Commitment to target area. A family, large corporation, local business, branch of government are or could be tied to a specific locale for a variety of reasons. One business may be totally reliant on the local area for all of its income, while another may not gain any of its income from its geographical location. Branches of state or federal governments could be intrinsically tied to a local area or just happen to be located in that community. Local governments are, obviously, dramatically tied to the local community. Ways in which commitment to the community at risk in an earthquake prediction affects decisions to reduce vulnerability and increase preparedness are presented in Table IV-8.

State and federal agencies, as well as local businesses, corporations and families, are more likely to relocate to an area of lesser risk if these units have little commitment or ties to the local community. For large corporations as well as small businesses, for example, the degree of economic dependency on the area at risk was negatively related to anticipated decisions to relocate (r = -.33). The same was the case for

TABLE IV-8

THE EFFECTS OF COMMITMENT TO TARGET AREA (ECONOMIC OR OPERATIONAL DEPENDENCY) ON EARTHQUAKE PREDICTION DECISIONS*

DECISIONS ↓	FAMILY	CORPORATIONS	LOCAL BUSINESS	STATE-FEDERAL AGENCIES - SERVICES	LOCAL GOVERNMENT AGENCIES - SERVICES
RELOCATION TO REDUCE VULNERABILITY	-	-	-	-	N/A
REDUCTION TO REDUCE VULNERABILITY	+	+	+	0	0
REALLOCATION TO REDUCE VULNERABILITY	N/D	+	+	0	0
RELOCATION TO INCREASE EMERGENCY PREPAREDNESS	N/D	+	0	0	0
REALLOCATION TO INCREASE EMERGENCY PREPAREDNESS	+	+	+	0	0

*N/A = not applicable; N/D = no data available; + = positive effect; - = negative effect; and 0 = no effect the relationship between the distribution of sales and services in the local area (r = -.45) and the moving of records. Economic dependency on the area at risk was also negatively correlated (r = -.37) with the curtailment/relocation of activities. These patterns were also exhibited for state and federal agencies located in the area at risk.

We have no way to speculate on how much of this relocation will go on, nor how much of it will be temporary versus permanent. We do know, however, that it is a possibility and that too much relocation could elicit negative secondary economic earthquake prediction effects in the local community. This need not be cause for alarm, however, because such effects are not likely to be of a great magnitude, such decisions will decrease vulnerability because people will move out of high risk areas, and such effects are likely to be short-term. Although commitment to the area at risk affects relocation for all types of social units (excluding local government bodies for whom as an explanatory factor it makes no sense), evidence suggests that permanent relocation will be very minimal. For example, only 10% of all the families interviewed thought they would even consider relocating permanently, although 50% said they would consider it if their employer moved. Few employers, however, saw permanent wholesale relocation as an option. Those who did were not committed to the local area (markets were national, little capital was invested locally or the physical plant was rented).

On the other hand, commitment to the area at risk, if relocation is blocked, serves to enhance actions to reduce vulnerability and increase preparedness. For example, for families, the longer the head of household was employed by his/her employer, the less desirable it was to change jobs, and the more desirable to increase savings to enhance emergency response and to decrease vulnerability. The same was true for having relatives in the immediate area, and for the other ways that familial links to the local community were measured. These patterns were the same for corporate and small business responses.

Resources to change. For all decision makers, choosing to reduce vulnerability and increase preparedness, is facilitated by the availability of resources, no matter which strategy is used (see Table IV-9). For example, in the study of Wilmington family response to prediction, income was positively associated with the purchase of earthquake insurance ($V = .21$), and with vulnerability reduction actions at home ($V = .23$) and at work ($V = .34$). Income was also related to emergency preparedness and vulnerability reduction decisions indicated by families in California. For organizations, resources were measured by size, budget flexibility, assets and profits. Consistently, for all types of organizations, and for most vulnerability reduction and increases in emergency preparedness behavior, resources were positively and significantly related to most response variables. The relationship of budget size and flexibility to response variables is illustrative: correlations were .44 to temporary relocation, .29 to reassignment of employees to an area of lesser risks, .66 to temporary curtailment of activities in the area at risk, .49 to decrease vulnerable inventory, .37 to increase staff size for earthquake related tasks, and .30 to arrange to share facilities in the emergency. These effects held even when other variables were controlled for in multivariate analysis.

In essence, resources for families are money, resources for businesses are money, and resources for government agencies are money. Without a program to make such resources available to all, the benefits of prediction (being able to take full advantage of knowing an earthquake is coming) will accrue to the affluent and not to the poor.

TABLE IV-9

THE EFFECTS OF RESOURCES TO CHANGE ON EARTHQUAKE PREDICTION DECISIONS*

DECISIONS ↓	FAMILY	CORPORATIONS	LOCAL BUSINESS	STATE-FEDERAL AGENCIES - SERVICES	LOCAL GOVERNMENT AGENCIES - SERVICES
RELOCATION TO REDUCE VULNERABILITY	+	+	+	+	+
REDUCTION TO REDUCE VULNERABILITY	+	+	+	+	+
REALLOCATION TO REDUCE VULNERABILITY	N/D	+	+	+	+
RELOCATION TO INCREASE EMERGENCY PREPAREDNESS	N/D	+	+	+	+
REALLOCATION TO INCREASE EMERGENCY PREPAREDNESS	+	+	+	+	+

*N/D = no data available; + = positive effect

Goal-Related Response and Negative Secondary Effects

The general model presented in Figure IV-1 suggests that an earthquake prediction-warning is information about altered earthquake threat. This new threat information will induce revised risk evaluations by people and decision makers and lead them to a range of new earthquake-related decisions. Some of these decisions will be followed by behavior which will work to increase emergency preparedness and decrease earthquake vulnerability. There are three responses (relocation, reduction, reallocation) to an earthquake prediction that can achieve two goals (reduce vulnerability and increase emergency preparedness). Several practical questions present themselves about the responses. Which strategies maximize the ability of the system to achieve the two goals? Which strategies maximize the potential for negative social and economic secondary effects (such as a decline in employment, tax revenues or retail sales)? We are able to provide only qualitative answers to these important questions.

It appears that negative economic secondary impacts will generally stem less from actions and behavior to increase emergency preparedness than from those taken to reduce earthquake vulnerability. Removal of people from the local labor force or the reduction in work activity in an area has the greatest potential for causing negative secondary effects. At the same time, however, actions to increase emergency preparedness through reallocation or relocation hold some, albeit lesser, potential for negative impacts. Action to increase preparedness by a local government, for example, by reallocating the city budget to heighten evacuation route planning at the cost of closing a library or collecting garbage less frequently, could have some negative effects. Such actions would not precipitate as large an economic impact, however, as a major local employer relocating to decrease vulnerability.

All five response strategies can cause negative economic impacts; however, some have greater potential than others:

MOST NEGATIVE IMPACT

1. Relocate to decrease vulnerability
2. Reduce to decrease vulnerability

LEAST NEGATIVE IMPACT

1. Reallocate to increase preparedness
2. Reallocate to decrease vulnerability
3. Relocate to increase preparedness

It is likely that negative impacts are more probable from actions to decrease vulnerability than from actions to increase preparedness because more institutional mechanisms are already in place for activities to deal with the latter. Police and fire departments, hospitals, state and federal agencies, private organizations, and many other means already are in place in the United States to plan and prepare for emergencies. Addressing emergency preparedness in an earthquake prediction need not require wholesale alterations of the status quo. However, earthquake vulnerability reduction is not as institutionalized, and, as a consequence, it requires larger efforts by all actors.

The Federal Emergency Management Administration (FEMA) has been charged with earthquake hazard vulnerability reduction. The California Seismic Safety Commission is, similarly, developing its strategy to reduce earthquake vulnerability in that state. Los Angeles has identified its high-risk buildings and initiated earthquake vulnerability reduction activities. As these sorts of activities become more entrenched and institutionalized in seismically risky communities, their potential for negative impacts will decrease.

A critical question for future research and policy is how incentives can be built which encourage increased emergency preparedness and decreased earthquake vulnerability and, additionally, low negative secondary impacts. Negative effects, in unspecifiable degrees, could alter (1) the availability of mortgage money, (2) property sales, (3) property values, (4) construction activity, (5) credit for durable goods, (6) local tax revenues, (7) provision of local public services, (8) employment, (9) population trends, (10) purchase and availability of earthquake insurance, and (11) the sale of durable goods, to name but a few.

Our inability to identify with confidence which and how many of these impacts will occur during a prediction is not important. Rather, because the factors have been identified which will cause different response behavior, policies can now push achievement of the goals of earthquake prediction and constrain the potential for negative secondary costs associated with some prediction responses. Issues and options for public policy are presented in the ensuing chapter.

Future Predictions and Likely Response

Because of the lack of experience with prediction, it is difficult to estimate fully the effect that changing one variable (e.g., length of lead time) will have on response. This section outlines a qualitative model designed to elucidate the effect that prediction parameters will have on response to a prediction. First, we discuss the parameters and the likely interactions among them, and second, we develop scenarios of likely predictions. Finally, a model is advanced to estimate the level of response generated by each alternative scenario.

Prediction Parameters

Five parameters of an earthquake prediction have been identified: probability, location, magnitude, lead time, and time window. In addition, two related elements--the credentials of the predicting person or organization and confirmation by others--are of importance. Table IV-10 provides a general view of how earthquake predictions may vary on each of these parameters.

TABLE IV-10

A SCENARIO GENERATOR: POSSIBLE VALUES OF PREDICTION PARAMETERS

Lead Time	Time Window	Magnitude	Location	Probability	Predictor Credentials	Confirmation and Consensus
LT-1 Several Years	TW-1 Not Specified	M-1 Not Specified	L-1 Vague-large area-(region)	P-1 Not Specified	Cr-1 High: USGS	CC-1 High
LT-2 Next Year or One Year	TW-2 A Year	M-2 "Damaging"	L-2 Near (city)	P-2 Vague and Low "a chance"	Cr-2 Good: Scientist	CC-2 Mixed
LT-3 Six Months	TW-3 Month of	M-3 R. mag. range 5.5 to 6.5	L-3 Specific Large area delineated	P-3 Vague and High "Likely"	Cr-3 Poor: Psychic	CC-3 Low
LT-4 One Month	TW-4 Week of	M-4 R. mag. 6	L-4 Specific Small area	P-4 20%		CC-4 None
LT-5 A Week	TW-5 Day of	M-5 6 to 8		P-5 50%		
LT-6 Several Days				P-6 80%		

As for predictors' credentials, it may be useful to distinguish among three levels: high, where the predictor is a well-known scientist or organization; good, where the predictor is a less reputable scientist; and poor, where the predictor has little or no scientific background or is a psychic. With regard to consensus, we can usefully distinguish predictions for which either a high degree, mixed, or low degree exists. In some situations, due to a political structure or small amount of lead time, the confirmation process will not be a functional aspect of a prediction.

Possible Future Predictions

It is valuable to distinguish between static predictions, that is, one-shot affairs in which information does not drastically change, and dynamic predictions. The latter involves an evolution of the prediction, perhaps days and hours ahead of the impact time. Based on prediction efforts to date and scientific developments over the past decade, Table IV-11 summarizes eight possible future predictions, six static and two dynamic. The parameters specified coincide with those outlined in Table IV-10, though other possibilities do exist.

The latest opinions suggest that the most likely predictions will be either a long-term dynamic prediction (#7), or a very short-term prediction (#4), or both. The efforts in Southern California to interpret the Palmdale Bulge may enable a long-term prediction in which scientific understanding is honed to the point where a more specific prediction can be made. At the other extreme, recent work measuring short-term precursors may lead to predictions with lead times similar to hurricane or riverine flood warnings.

Parameter Variation and Human Response

As the parameters of a prediction change, or as conditions posed by alternative scenarios differ, so too will human response. Certain

TABLE IV-11

SEVERAL POSSIBLE PREDICTIONS AND THEIR PARAMETERS

Type ↓		Lead Time	Time Window	Magnitude	Location	Probability	Credibility	Confirmation and Consensus
A Long-term General Prediction		LT-1 2 or more years	TW-1 Not Specified	M-2 Damaging	L-1 Large Area	P-2 A Chance	Cr-1 High	CC-1
A Long-term Prediction w/ Mixed Reactions		LT-1 3 years	TW-2 1 year	M-5 6-8R	L-3 Area w/ 100 mile diam.	P-6 80%	Cr-1 High	CC-2 Mixed
Medium Range w/o Prob.		LT-2 1 year	TW-2 1 year	M-2 Damaging	L-2 Near	P-3 Likely	Cr-2 Good	CC-2 Mixed
Short-term Credible		LT-6 Several Days	TW-5 Day of	M-5 6-8R	L-4 Specific Area	P-6 80%	Cr-1 High	CC-4 Not Suff. Time
Short-term Non-scien-tific		LT-5 week	TW-5 Day of	M-4 7.5	L-4 Near	P-3 Likely	Cr-3 Poor	CC-3 Low
Medium Range w/o Validation		LT-3 6 months	TW-3 Month of	M-3 5.5-6.5	L-3 Specific Large Area	P-6 80%	Cr-1 High	CC-3 Low
Long-term Dynamic	Start	LT-1 LT-1	TW-1 TW-2	M-1 M-2	L-2 L-2	P-1 P-3	Cr-1 Cr-1	CC-1 CC-1
	Finish	LT-2 LT-4	TW-2 TW-4	M-5 M-5	L-3 L-3	P-5 P-6	Cr-1 Cr-1	CC-2 CC-2
Short-term Dynamic	Start	LT-5 LT-5	TW-4 TW-4	M-2 M-5	L-1 L-4	P-3 P-3	Cr-1 Cr-1	CC-1 CC-1
	Finish	LT-6	TW-5	M-5	L-4	P-3	Cr-1	CC-1

parameters will enhance or detract from the suitability of a given response. Variations in parameters could conduce to a particular action or change behavior in general terms.

Beyond what has been already discussed, little more in the way of empirical evidence can be mustered. We can, however, offer some educated estimates of various interactions between prediction parameters and response. Table IV-12 summarizes our estimates of the effects changing parameter values will have on the appropriateness of the five response strategies. The arrows indicate how the propriety of each general category is affected as the parameter increases in value (lead time and time window lengthens, location grows larger, magnitude increases, etc.). Arrows in more than a single direction indicate uncertainty or a range in possible impacts. The table permits comparison of variations in categories by columns vertically or horizontally, and scrutiny of individual cells.

Table IV-13 reviews the effect that variance in parameters will have on the likelihood people will respond to an earthquake warning. Again we distinguish between parameter value and the degree of precision with which it is stated or presented to the public. While these represent general tendencies, the relationships are by no means necessarily linear. It will take either many predictions or a great deal of work in controlled experiments to reveal the strength and nature of how parameter changes link with the level of human response.

TABLE IV-12

ESTIMATED RELATIONSHIPS BETWEEN PREDICTION PARAMETERS AND RESPONSE STRATEGY APPROPRIATENESS*

Appropriateness of Activity ↓	As Parameters Increase (in size and degree of specificity)						
	Lead Time	Time Window	Location	Magnitude	Probability	Credibility	Confirmation and Consensus
Relocation to Reduce Vulnerability	↗	↘	↘	↗	↗ / →	↗ / →	↗
Reduction to Reduce Vulnerability	↗	→ / ↘	↗ / →	↗	↗ / →	→	↗
Reallocation to Reduce Vulnerability	↗	↗ / →	→	↗	↗	→	↗
Relocation to Increase Emergency Preparedness	↗	→ / ↘	↘	↗ / →	↗	↗ / →	↗
Reallocation to Increase Emergency Preparedness	↗ / →	↗ / →	↗ / →	↗	↗	→	↗ / →

* ↗ = increase; ↘ = decrease; → = not greatly affected

TABLE IV-13

ESTIMATED EFFECTS OF VARIANCE IN
PREDICTION PARAMETERS AND PROPENSITY TO RESPOND*

	Lead Time	Time Window	Location	Magnitude	Probability	Credibility	Confirmation and Consensus
Propensity as Value Rises	↘	↘	↘	↗	↗	↗	↗
Propensity as Vagueness Rises	↘	↘	↘	→	→ ↘	→	→ ↘
Relative Weight for Credibility**	.30	.30	.40	.35	.45	1.0	.05

* ↗ = increase; ↘ = decrease; → = not greatly affected

**Based on empirical evidence

CHAPTER V

ISSUES AND OPTIONS FOR PUBLIC ACTION

Earthquake prediction holds great promise of societal utility, and is well worth the cost of development, only if work is begun now to research, draft and implement the political and administrative policies necessary for effective use.

We have assembled information about the range of issues that will influence people and public and private decision makers as they respond to a scientifically credible earthquake prediction. However, earthquake prediction can only be efficacious if there are changes in policy to insure that the benefits of using the technology exceed its costs. On the basis of our findings, there are four arenas in which policy could help maximize the benefits promised by prediction: delegation of responsibility, insurance, resources and information.

Delegation of Responsibility

The earthquake prediction-warning system in the United States is being built in the image of warning systems for other natural hazards. Faults in the systems for other hazards, unfortunately, will also exist in the emerging warning systems for earthquakes. Many lessons learned from the study and use of other warning systems, for example, weather-borne hazard warning systems, are being ignored. The knowledge gained from experience with other warning systems should be used on the earthquake prediction-warning system.

Nowhere are warning system faults more obvious than in reference to the integration of the three basic elements of a warning system: detection, dissemination and response. The nation spends millions of tax dollars each year to detect weather-borne hazards; it spends considerably less, however, getting appropriate warnings to people in their homes when, for example, a flash flood is a few minutes away (Mileti, 1975). No one agency has responsibility for the effectiveness of weather-borne hazard warnings, which can only be measured in terms of human response. In the absence of ultimate responsibility, or at least a person or two who define it as their full-time job, breakdowns in the operations and linkages among the three functions of warning systems sometimes do occur. Such breakdowns result in more disaster costs than necessary because public warning response is left to local chance. Earthquake prediction-warning systems in the United States need not be plagued by this fault at a time when groups responsible for other kinds of warning are making advances in integrating their systems, for example, the National Weather Service, in the National Oceanic and Atmospheric Administration.

USGS Responsibility

As the nation designs and builds its earthquake prediction-warning system, the key national earthquake detection agency, the United States Geological Survey (USGS), must be made responsible for warning response. The National Oceanic and Atmospheric Administration (NOAA) takes into account that response in all its warning activities; the nation copes with weather-borne hazard losses better because of NOAA's efforts. It is inconceivable to expect the USGS to have complete responsibility for response in the possibly long-term earthquake predictions because they could have larger secondary negative socioeconomic impacts. Yet, the USGS is headed down the same responsibility-free path traversed, unknowingly, by NOAA when weather-borne hazard warning systems were drafted into policy. This dramatic mistake can be avoided, especially because recent NOAA advances toward warning system integration could serve as a model.

The USGS should be charged to expend some of its earthquake prediction effort and resources on work to assure that its predictions of earthquakes will accomplish more than chance public and private response. This need not entail more than directing the USGS, through cooperative work with state and local governments, to provide the technical assistance needed in a prediction-warning setting to assure appropriate local earthquake prediction-warning response. This opportunity to integrate the earthquake prediction-warning system can be readily and inexpensively realized through a variety of alternative strategies.

Within the Department of the Interior, Congress, or within the Survey itself, it could be decided to create a prediction-warning response division, department, office or person within the Survey. This "consequences branch" of the Survey, which could well be housed in Menlo Park where prediction technology development is headquartered, could operate and be structured in a variety of ways. It could be an office of a few technical experts to conceive, oversee, or perform research and work. It could as easily be a staff whose job it is to do the work itself. Information must be assembled and organized that will improve both the technical assistance the USGS could provide to state and local entities if there is a prediction, as well as the structure and means whereby the Survey and these entities will cooperate to upgrade prediction response.

We do not suggest that the USGS take charge of states and local communities for which they issue a prediction. Rather, because local areas can only address prediction-related issues when a prediction is issued and the USGS deals with predictions daily, we suggest only that the Survey begin to provide a state or community with prediction-response information and to be the place where a person or two has the job of thinking about how to integrate the earthquake prediction-warning system. This effort should augment and assist the efforts of state and local emergency response agencies.

Other Agency Responsibility

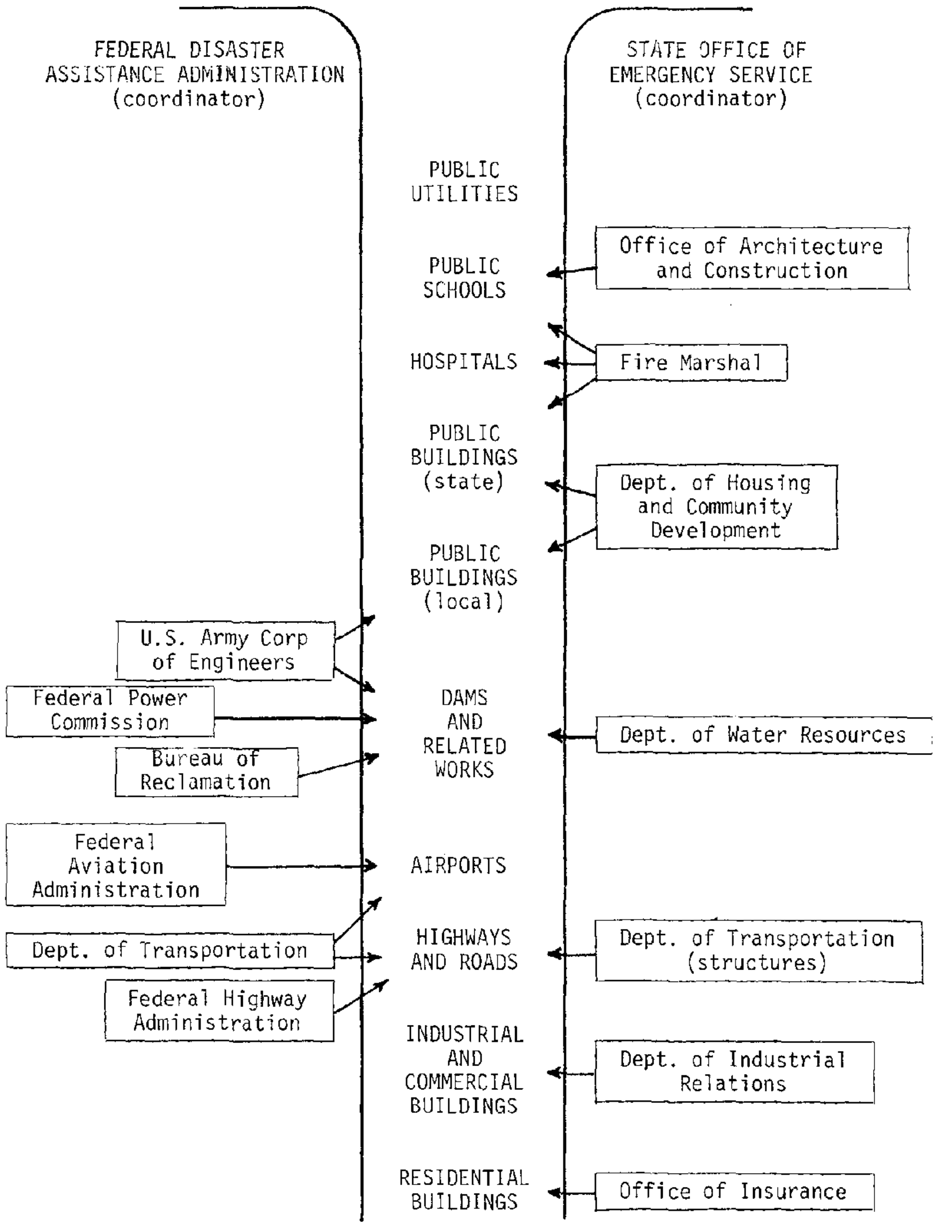
An earthquake prediction will turn everyone, to some extent, into a risk assessor. Some individuals and groups will have greater responsibilities than others for providing information or assessing risks. At the same time, some individuals and groups will have a greater capacity for understanding and utilizing risk information than others.

Who will make risk assessments and provide risk information is a key question for policy makers. In the public sector, risk information will come from individuals and agencies in different parts of federal, state and local governments. Within the private sector, risk information will originate from both professionals and amateurs, including the soothsayer and the local barber. Figure V-1, based on our data, depicts the responsibilities agencies perceived for assessing the physical vulnerability of various segments of the built environment. These agencies vary in abilities and the extent to which they can provide risk information. It is apparent that there is a different degree of interest in the various parts of the built environment. For example, four agencies (see Figure V-1) said that they would assess the vulnerabilities of dams and related engineering works; however, only one agency was interested in schools and hospitals. When capability to evaluate risk is also considered, an even greater difference emerges. Because of the structure of government agencies, there will be uneven efforts to assess risks from a predicted earthquake.

A second problem will be coordination among risk assessors. Risk assessing will be a function of perceived organization role, competition, and limited resources. For example, in our interviews with public agencies, we frequently found that Agency A said it was not responsible for determining the safety of hospitals, but Agency B was. Yet Agency B did not perceive that duty as part of its responsibility. This problem

FIGURE V-1

THE ASSESSORS:
A VIEW FROM THE FEDERAL AND STATE GOVERNMENTS



is exacerbated when, for instance, the hospital officials do not know who is responsible for providing information or assessing risk. This can be avoided by enlarging the present scope of emergency preparedness planning to include clear definitions of agency responsibilities during a prediction.

Another problem arises from the fact that agencies have overlapping or competing interests. Coordination is required so that multiple assessments are not made of one structure and other structures are ignored. Coordination will be made more difficult by limited resources and time. The shorter the lead time of a prediction, the fewer risk assessment activities possible. In the short run, evaluating vulnerability to the predicted earthquake may be hampered because that competes with agencies' existing missions and duties.

Few local agencies assumed they would take responsibility to assess risk; most would wait for risk information to come from elsewhere. No local agencies who did anticipate performing risk assessments planned to coordinate those activities with state and federal efforts. All were confused about legal obligations to perform such assessments or not.

Engineering and geotechnical firms represent the involvement of the private sector in risk assessment. They will be capable of generating risk information. Additionally, many large utility companies have sufficient expertise to do so. More difficult to identify and regulate are the activities of soothsayers or others without engineering expertise.

Policy and methods must be developed to improve risk assessment activity in an earthquake prediction. Which agency at which level of government should assess the risk to which public structures are exposed is not well defined. Responsibility should be delegated now to facilitate risk assessing in an earthquake prediction setting. The role of private companies in assessing risk also should be specified.

There are local and state associations, for example, the Council of State Governments and the Association of Bay Area Governments, which could examine the risk assessment responsibilities of the varied branches of state and local government. Federal agency responsibility could be formalized through a task force, perhaps housed in the Federal Emergency Management Agency (FEMA), with representatives of the federal agencies which could or should be involved in assessing risk in an earthquake prediction.

Means of making citizens better risk assessors should be explored. For example, home earthquake prediction interpretation guides could be prepared. Such guides should reflect the new understanding of the problems people have in working with risk concepts (Kates, 1978; Whyte and Burton, 1980). Another useful item would be a home safety evaluation kit which would allow homeowners without technical backgrounds to determine the safety of their residence without great investments of money or effort.

Insurance

Our analyses suggest that with more earthquake and related kinds of insurance in effect in a community for which an earthquake has been predicted, fewer steps will be taken by businesses to reduce losses. Insurance may act as a constraint to achieving one of the two main goals of earthquake prediction technology--vulnerability reduction.

There should be requirement in an insurance program to encourage adaptive response. Federally subsidized earthquake insurance would best be structured similarly to the National Flood Insurance Program. That program requires that land use controls be adopted and implemented in a local community in order for it to remain eligible for federally subsidized flood insurance. Most communities will pass local ordinances in order to be in compliance with the NFIP.

Such a program, however, must be thoroughly reviewed and appraised so that requirements and sanctions have a maximizing effect on other vulnerability reduction strategies, and a minimizing one on constraining the purchase of insurance in the first place. Review of these issues by the Federal Insurance Administration and state insurance commissions is warranted, and consideration given to the difficulties encountered by the National Flood Insurance Program in administering negative sanctions to local governments nationwide.

Resources

Our data indicate that those with money will accomplish much in a prediction, and those without money will be able to do little. There should be a program to make additional resources available in a prediction-warning setting to those who need them, be they families, small businesses or governmental agencies.

A legitimate earthquake prediction, which provides enough time for effective reduction of vulnerability, should be cause for before-the-event federal assistance for vulnerability reduction and emergency preparedness. Legislation is needed to make such a prediction cause for FEMA, FHA and SBA, for example, to proceed as they would after the earthquake does occur. The extent to which federal involvement is practicable in earthquake hazard mitigation on the basis of an earthquake prediction is, however, not easily specified. It would be foolish to spend billions of tax dollars to reduce vulnerability and increase preparedness in, for example, Los Angeles, on the basis of a 6.1R earthquake prediction. It is equally imprudent, however, to let a resource constraint hold back actions to reduce vulnerability and increase preparedness after spending millions to develop the technical capacity to make the prediction in the first place.

A practicable federal role lies somewhere between these two extremes. Definition of that role must not be left until the chaotic time following a prediction. Too many federal disaster resource policies are assembled in the altruistic political climate typical of the aftermath of disasters (Mileti, 1975). FEMA could be charged with investigating the nature, mechanisms and extent of federal assistance, given alternative prediction scenarios, to be used in concert with earthquake prediction technology.

Information

Chapter IV of this work illustrated that information bears on policy considerations in three general areas: understanding prediction technology, understanding earthquake risk, and equity in access to information.

The public must not be sheltered from trial predictions, hypotheses tests and the like to avoid negative impacts as the technology develops. It is incorrect to assume that the public would panic and undue costs would be incurred. Additionally, many valuable lessons can be learned that could upgrade the quality and quantity of response to some future potential prediction for a great earthquake.

The family respondents in our study indicated that the public is not likely to over-react to a prediction. Indeed, the problem with earthquake prediction-warning systems may be getting the public to respond at all, the same problem with warning systems for other infrequent natural hazards (cf. Mileti, 1975). Public understanding of the development of the new science of earthquake prediction is important. In the long run, open publicity of the science will alleviate some of the natural reluctance of warning officials and make their judgment responsibilities easier to live with. A candid approach to the release of prediction information allows the public to learn with the scientists. Policies which support the above activities must be maintained.

Understanding Earthquake Risk

No one policy-relevent element is more important to facilitating accurate earthquake risk definitions than the improvement of accurate methods to portray image of damage and risk.

Image of damage. Our research leads us to conclude that image of damage is directly and positively related to all decisions and subsequent actions, for public and private decision makers alike, for both vulnerability reduction and emergency preparedness decisions, for relocation, reduction and reallocation strategies. The more damage anticipated, the more likely it is that people will decide to reduce vulnerability and increase emergency preparedness: people will make decisions about what to do in response to a prediction on the basis of what they *think* will happen if and when the predicted earthquake strikes. Appropriate and balanced response to an earthquake prediction-warning will only proceed on the basis of widely held *accurate* (or at least reasonable) images of damage by both public and private decision makers. Only accurate images will allow the benefits of the technology to be maximized while imposing costs due to secondary negative impacts well worth the benefits gained.

Inaccurate images of damage will arise from the following: (1) a general tendency for people to deny the risk of hazards to themselves and their possessions, (2) a surge of media attention to pictures and accounts of earthquake damage from other quakes, even though building designs, magnitudes and intensities of these quakes were different from the predicted quake, (3) past earthquake experiences or complete absence of experience in the population, and (4) numerous conflicting damage maps for the predicted earthquake.

Policy can be formulated on two issues to enhance accurate images of damage in an earthquake prediction: the issuance of damage maps and earthquake damage information packages.

(1) damage maps. Our evidence suggests that a variety of damage maps will appear after a prediction. Some will be official and others will be unofficial. The newspaper that can't get a map from the USGS by press time will get one from, for instance, a university, or draw one itself. Psychics will contribute maps, as will realtors, cities, the state and the USGS. To compound this confusion, the maps will change as they are updated to reflect new data on the prediction.

An additional problem will be the delineation of high, moderate and low damage areas. It is inappropriate, given the uncertainties involved, for areas of a community which have very low probabilities of experiencing damage to be labeled damage-free. If some decision makers are led to believe that there is very low risk, they will see no need to engage in vulnerability reduction or emergency preparedness. To the extent possible, the definition of low risk and no risk areas must be specified clearly if uncertainty does exist.

A professional board to review or construct damage maps would be desirable; furthermore, the possibility of having one state-sanctioned map source should be investigated. The public would know which source was preferred and used by the state. Such an officially sanctioned map should be made available quickly to reduce the number of conflicting unofficial maps that will emerge. As time passes in the prediction period, refinements of this map based on additional scientific data will be necessary. A revision, however, need not be a statement to people that decisions made on the basis of "out-dated" maps may have been inappropriate. Risk perception is a continual process and new information must be dealt with. The public can be educated to this reality.

The job to construct or review a damage map early in the prediction period is challenging. Policy should be formulated now to expedite the provision of officially sanctioned damage maps in an earthquake prediction.

One alternative in California would be to charge the Seismic Safety Commission with issuing the damage maps in a prediction. Market research on how people understand and use hazard risk maps would greatly aid any efforts in this direction.

(2) earthquake damage. Accurate images of damage could also be insured following a prediction and warning through the use of information packages which detail what kind of damage occurs in the U.S. with earthquakes of different magnitude and intensity, with U.S. building designs, what earthquakes do not do, and what percentage of a community's structures could be affected and to what degree. In the absence of such packages, images of damage will be formed on the basis of how readily available pictures of earthquake damage in other countries, with other magnitudes and intensities, or of historic earthquakes.

These information packages should also take into account that many people do not understand the meaning of earthquake magnitude or intensity. The clearest possible definitions must be used. For most people, the Modified Mercalli scale may be most relevant because it expresses the action of an earthquake in more understandable terms. Few people readily understand probability concepts, but predictions will be full of alternative probabilities. Methods must be developed to enhance public understanding of probability concepts.

There is now no mechanism for getting this information out after a prediction. What information is needed, and the alternative ways by which it could be made public after a prediction, could be addressed now because most information needs are related to things we already know about earthquakes in general, for example, what kinds of structures typically are least affected. Current public earthquake education programs could incorporate these few concepts into their campaigns. Since such information already exists, it could be assembled by, for example, the U.S. Geological Survey or the Governor's Office of Emergency Services in California, for release to television, radio, newspapers and public assemblies immediately after a prediction, and to schools now.

Risk. As current efforts to assess the level of generic earthquake risk through regional or local studies or through microzonation proceed, the ability to respond well to a prediction will be enhanced. Such efforts will provide more specific risk information in a prediction setting. The same is true for other ways to define earthquake risk independent of prediction, for instance the monitoring and inventory of structures and property at risk, and the distribution of that risk. A mechanism should be developed for incorporating available risk information from such efforts into prediction preparedness planning.

Equity in Information Access

Everyone will not have equal information and accurate knowledge in a prediction-warning. There will be inequities in both access to information and the ability to respond to that information.

Our data on family response were analyzed to determine if preferred sources differed along measures of socioeconomic status. Results were compared to the existing structure of earthquake information dissemination to determine if de facto inequities exist. They seem to infer from our analysis that high status groups will be more apt to respond adaptively to earthquake warnings emerging from the probable givers of such warnings than persons of lower social status. The same problem of inequity was revealed in our study of organizational response to a hypothetical prediction. Limited access to information will constrain many organizations from taking appropriate prediction-warning response.

This problem is complicated by the large variance in the population on ability to process risk information once it is received. Persons and groups with greater access to technical expertise--the affluent--or the education to process such information--the affluent--will be able to make decisions more reflective of the risk and uncertainties associated with the predicted earthquake.

Information must be (1) written or prepared in different ways such that different kinds of people and groups all *perceive* the problem accurately, and (2) presented or delivered in different ways such that different people and decision makers who have different levels of access to information have a relatively good chance of receiving the information. Information or warning systems specialists could prepare the content and design delivery systems for this information with increased knowledge of who needs to be provided with what.

APPENDIX I

SCENARIO METHODS

The claim has been made that the usefulness of scenarios is the assistance they provide to the decision maker for preventing, diverting or encouraging the evolution of a social system at specific points in time (Kahn and Wiener, 1967: 6). Policy-relevant scenarios are defended by their proponents as useful in revealing the future differences between alternative present decisions (Bell, 1964: 873), including the decision to not initiate any change (Durand, 1972: 328).

In recent years, the writing of alternative futures or scenarios has increased (cf. Bell, 1964: 866). Their purpose has, however, been expanded beyond the explication of future possibilities to use as a tool for decision making. Some uses of scenarios extend into future forecasting which Bunge (1967) has called prognosis. Ericksen (1975: 12) has referred to such scenarios as commonsense forecasts made with the help of empirical generalizations. Such scenarios are logically constructed. The degree of confidence in the constructed progression of events and outcome typically remain undefined (Jantsch, 1967: 15). The probability of the sequential series of events occurring through time must, however, decrease as subsequent events build on prior cause.

Whether viewed as exploratory possibilities, forecasts or normative visions (Polak, 1971: 402), the ever-expanding use of scenarios suggests the need for appraisal of the uses and abuses of scenarios in policy research. It is this appraisal which this preface to our scenario seeks to explore. Scenarios have largely been used and abused in policy research in two ways: to disseminate research findings, and as a method to generate them.

As a means for disseminating and illustrating research findings and hypotheses, scenarios are effective attention-getters. Like constructs, scenarios are useful to decision makers not because they are true, but because by thinking about them some truths or new policies may be derived.

As constructs, scenarios are effective devices for increasing awareness and in educating decision makers to the range of possible consequences of a decision or the advent of a new technology, the onset of a rare event or in highlighting their negative and positive, direct and secondary effects to a given social system.

Scenarios, however, are not true stories; they may not even be probable stories. It is therefore imperative that the researcher who uses scenarios as a means to present study findings as hypotheses must inform the policy maker that there are limitations on their use as a basis for planning (White, 1976).

Research on the problem of interpreting the probabilities suggested in scenarios illuminates this potential abuse of an otherwise good educative tool. Slovic, *et al.* (1976) are exploring the role that the psychological study of decision making processes can play in improving societal risk taking. They have pointed out that despite the highly sophisticated methods for collecting information and constructing technological solutions, decision makers ultimately rely most on their intuition; this tendency limits the quality of the entire decision process.

Scenarios consist of a series of events linked together in narrative form. Normatively, the probability that a multi-event scenario will happen is a multiplicative function of the probabilities of the individual links. The more links there are in the scenario, the lower the probability that the entire scenario will occur. Furthermore, the probability of the weakest link sets an upper limit on the probability of the entire narrative.

The caution regarding the use of scenarios for more than a sensitizing, educative tool is strengthened by Slovic's further research:

"Human judges don't appear to evaluate scenarios according to these normative rules." His studies currently suggest that the probability

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