Mass Emergencies 1 (1976) 179–202

EARTHQUAKE PREDICTION AND PUBLIC POLICY: DISTILLATIONS FROM A NATIONAL ACADEMY OF SCIENCES REPORT [1]

Ralph H. Turner
University of California, Los Angeles

By 1973, accumulating empirical evidence and a promising theoretical break-through (Scholz et al., 1973) had made the imminent prospect of earthquake prediction credible. Concerned scientists and public officials quickly began asking what should be done if the premonitory signs of a potentially destructive earthquake were detected for a heavily populated area. When and how should the prediction be released? Was there a real danger that releasing the prediction would provoke mass panic, public disorder, and economic disaster? What steps might be taken in order that the community would benefit from a period of advance warning? Such conerns as these led to the establishment in April 1974, of the Panel on Public Policy Implications of Earthquake Prediction, within the National Academy of Sciences. The Panel was mandated to

> provide advice to the Federal Disaster Assistance Administration, Department of Housing and Urban Development, that will serve as a basis for the formulation of public policy relating to an expected earthquake prediction capability. The types of governmental response with which the Panel will be concerned include warning of public officials and of the general public; governmental actions to mitigate the loss of life and property; and the need for further studies and research.

The resulting report was an effort to combine principles from several behavioral sciences with insights from practical experience in disaster planning. Although it highlighted problems for investigation by behavioral scientists, the report was primarily intended for use by decision-makers in federal, state, and local governments and in private agencies; by leaders in the business community and other parts of the private sector; by scientists and engineers concerned with disaster prevention, mitigation and preparedness; and by interested citizens.

The work of the Panel can be summarized under four broad sets of questions. First, what are the policy-relevant characteristics and circumstances of prediction likely to be, what are the main hazards of earthquakes, and what might be the elements in a constructive response to prediction, taking account of the identified hazards? Second, what do we know about response to warnings of disaster that might help in planning for the constructive release of predictions? Third, what economic and legal implications of prediction and what potential problems of inequity must be taken into account in planning a constructive response? And what complications should be anticipated as response planning becomes enmeshed in the political process? Finally, what concrete actions might be taken in response to an earthquake prediction, and what conclusions and recommendations can be drawn from the entire investigation?

EARTHQUAKE PREDICTION AND HAZARD

Prediction

Non-specific forecasts, such as the warning that a major earthquake is bound to occur along the southern California section of the San Andreas fault within fifty years or a century, and risk mapping that identifies faults along which earthquakes seem most likely to occur are already familiar to the denizens of earthquake country. But the new prospect is for predictions that specify the place, time, and magnitude of the quake within fairly close limits. Unlike the older procedures, prediction depends upon detecting premonitory signs, such as surface tilting and changing physical properties of rocks under stress, that occur in advance of a specific quake. Although earthquake prediction is still in a research and development stage, and instrumentation is too sparse in most locations to insure detection of premonitory signs, a few quakes have already been convincingly predicted, and impressive evidence from the Soviet Union, Japan, and China reveal precursors similar to those observed in the United States.

The following anticipated characteristics of earthquake prediction (Greensfelder, 1974; Kisslinger, 1974; Scholz et al., 1973) seem especially relevant for policy considerations. (1) For earthquakes severe enough to subject communities to substantial risk, premonitory signs should be observable months or years before the event. The prospect of long lead times makes earthquake prediction quite different from such familiar occurrences as flood, hurricane, and tornado warnings. (2) When instrumentation is adequate and sufficient baseline data have been accumulated, the prediction lead time should increase with the quake's magnitude. Lead times as long as ten to forty years have been projected hypothetically for major earthquakes. (3) Assurance and specificity of a given prediction will probably improve incrementally over an extended period of time, starting with ambiguous and incomplete signs of tectonic stress. Accordingly it is impractical to think of withholding information until some strategically selected moment when the refined prediction can be issued in its final detail. (4) At present it appears that not only the lead time but the length of the *time window* for a prediction will vary directly with the impending quake's magnitude. In the case of major quakes, it may only be possible to specify the time of predicted occurrence within a time window of from one month to even a year or more. Unless the time window is narrowed, short-term remedies such as evacuation, closing down essential services, and maintaining key personnel on round-the-clock alert status may be infeasible. (5) Unlike floods, hurricanes, and tornadoes, earthquakes are preceded by no external signs through which the public can make their own informal confirmations of the prediction or identify the moment of occurrence. Hence earthquakes will be distinctive among natural disasters in the extent to which public response will depend exclusively on the faith people place in scientific prediction. (6) Minor quakes occur frequently, while potentially destructive quakes in any specific locality are usually separated by decades. If many small quakes are successfully predicted, people will become accustomed to prediction without being prepared to deal with the infrequent serious quake. Because of the long intervals, every prediction of a serious quake is likely to be the first such experience for most of the inhabitants of the affected area and for most of the personnel charged with preparing for the event. Hence there is little hope of accumulating experience within the local community for dealing with predictions of significant quakes. (7) Within the foreseeable future, it is unlikely that predictions can be made with a high degree of certainty, and likely that some quakes will occur without being predicted. Nonscientific predictions will surely multiply as public awareness of prediction capability increases. Hence earthquake prediction seems

sure to be plagued by problems of public credibility. (8) The hope has been voiced that seismologists might sometimes issue negative predictions, i.e., assurances that an area will be free from damaging quakes for some specified period, or that certain predicted quakes and their aftershocks will "immunize" the area for several decades. For the present, neither the evidence nor the understanding of seismic phenomena will justify such assurances. (9) Although there is some hope for an eventual earthquake control capability, there is no realistic prospect of having such operational capability in time for inclusion in the current armory of responses to prediction. (10) Present understanding of earthquake precursors in the United States applies best to the Western states, but the earthquake hazard exists in such widely dispersed areas as Missouri, South Carolina, and Massachusetts. (11) Understanding of premonitory signs is an inevitable by-product of research into earthquake dynamics. While we might slow down the refinement of earthquake prediction capability by enforcing a policy against further efforts to achieve prediction, we cannot stop it. Hence we now have no choice but to accept earthquake prediction capability as an accomplished fact and seek to make the most constructive possible use of it.

Earthquake Hazard and Constructive Response

The primary effects of earthquakes are death, injury, and suffering; damage to systems and structures; and disruption of normal activities. Most deaths and injuries are from collapsing structures, falling debris such as bricks and glass, tsunamis, land slides, floods from collapsed dams and levees, earthquake-induced fires, and release of toxic, chemically reactive, and radioactive materials. It is important in planning the response to earthquake predictions to realize that people can be relatively safe in the earthquake vicinity if they are at a safe distance from these largely man-made hazards.

In California, where seismic safety standards have been incorporated into building codes since 1933, a sizable fraction of the population still live and work in unsafe structures. In other regions of the United States there are relatively few buildings except modern high-rise structures that have been constructed with earthquake resistance in mind. There is still much to be learned about earthquake-resistant construction, especially in relation to those very infrequent quakes classified as "major". Lifelines, which include transportation, communication, energy, and water systems, are particularly vulnerable in earthquakes. The collapse of a single bridge, or the rupture of an aqueduct, natural gas line, or power line, threatens normal life processes in an entire community. Since most existing facilities were not built for seismic resistance, lifelines demand special attention when an earthquake is imminent.

Given an earthquake prediction, what new measures can be taken to reduce the deaths, injuries, property losses, and disruptions just enumerated? What more can we do if we are given advance warning of the approximate place, time, and magnitude of an impending quake than we could have done without the warning? The measures making up a complete program for utilizing an earthquake prediction can be grouped under five headings:

1. Authenticating and issuing predictions and warnings;
2. Implementing a hazard-reduction program to minimize the loss of life and property and community disruption when the quake occurs;
3. Readying emergency services to deal with the situation after the quake has occurred;
4. Controlling and offsetting potentially counterproductive consequences of the prediction;
5. Pre-prediction planning for each of the foregoing sets of tasks.

In the following sections, we shall take up these tasks in order, except that pre-prediction planning will be discussed simultaneously with each of the other topics.

ISSUING PREDICTIONS AND WARNINGS

Responses to Warnings of Disaster

Early in the Panel's deliberations we found it helpful to distinguish between predictions and warnings. A *prediction* is a neutral statement indicating that an earthquake of a specified magnitude will probably occur at a specified location and time. A *warning* is a recommendation that normal life routines should be altered for a time to deal with an impending danger. Predictions are based on scientific analysis of signs known to have preceded earthquakes in the past. They say nothing about how people should respond, and are unaffected by public policy considerations. Warnings will follow some, but not all, predictions. Based on assessment of the prediction and the associated conditions, a warning identifies the situation as one of danger, in which the risk to life and property can be reduced by appropriate response.

A crucial policy question is how to release earthquake predictions and issue warnings in such a way that the response will be constructive and not counterproductive. Because there have been no previous opportunities to observe how people and organizations respond to earthquake predictions and warnings, we must turn to analogous events in seeking answers to the question. Three sources appear to be relevant:

(1) previous studies of response to warnings in other types of disaster;

(2) analyses of long-term disaster-preparedness problems; and

(3) analyses of such slowly developing social problems as the energy and environmental crises.

(1) Research into a variety of wartime and peacetime disasters has revealed a widespread proclivity to suppress predictions of danger and delay the dissemination of warnings until it is too late for maximum benefit. A stereotyped belief that people will panic when warned of danger is often the reason for suppression and delay. But the findings from this same body of research are that most people do not respond to disaster warnings with panic, hysteria, or other non-rational or uncontrolled forms of behavior, and that "mass panic" is largely a figment of the imagination (Fritz, 1961; Quarantelli and Dynes, 1972). A more likely response derives from the "normalcy bias" (McLuckie, 1973, p. 22), i.e., the tendency for people to accept most readily any information that enables them to disbelieve the prediction, minimize the danger, and view the situation optimistically. The ambiguities in the predictions released during the next decade or more will provide adequate scope for wishful disbelief, and long lead times can make the danger seem too remote to require action.

The response to warnings will vary by community and group. Groups with recent disaster experience are more likely to respond constructively to warnings (Anderson, 1970). "Disaster cultures" (Moore, 1964; Dynes, 1974) develop in areas exposed to recurrent disaster threats, with the result that public officials and citizens alike show a high degree of sensitivity to the threat of disaster. At present we have little evidence of a well-developed "earthquake culture" to compare with the consciousness of risk in coal mining communities or tornado country, even in California. But it is likely that Californians, Alaskans, and Hawaiians will more readily assign credibility to an earthquake prediction and participate cooperatively in community response plans than people in Missouri, South Carolina, or Massachusetts. Experience can also have a lulling effect. Most California communities have been subjected to only minor earthquakes for several decades, and many inhabitants may take an earthquake warning lightly because of this past experience.

Existing disaster studies indicate that elderly people, the handicapped, persons of low socioeconomic status, and members of minority ethnic and foreign speaking groups are least like-

ly to receive, understand, or believe disaster warnings. Because of past grievances and hostilities, many members of minority groups will assign little credibility to the official sources that disseminate warnings, and consequently will not be disposed to take appropriate precautionary actions.

Popular disbelief and inaction will be enhanced if public officials delay issuing warnings or attempt to suppress predictions until they can be quite certain that the danger is real. Officials will be concerned about what false alarms might do to their credibility and future effectiveness, possible legal problems associated with erroneous predictions, and potential disruption of the local economy. At the same time they must realistically take notice of the uncertain and imprecise nature of the early predictions. Based on these considerations and evidence of official behavior in other types of disaster warning situations, Haas (1974, p. 50) has hazarded the guess that "Public officials in the areas to which the forecast applies will try to avoid taking a position publicly on the probable validity of the forecast. To the extent that this is impossible, their comments and actions will tend to undermine the credibility of the forecast."

The situation will be further complicated when national attention focused on the designated area leads to a "convergence" of people and messages toward the threatened area or toward centers of information and communication in or near the area (Fritz and Mathewson, 1957). Visiting scientists, government officials, mass media representatives, businessmen, and the general public may deluge the agencies responsible for predictions and warnings with requests for additional information. Curious outsiders will tour the threatened area, and thrill seekers will converge as the predicted time approaches. Such convergence responses may temporarily overload transportation and communication networks and tax the work capabilities of agencies involved in planning and executing responses to the earthquake warning.

It is important that we remember that the experience with disaster warnings on which we based the preceding discussion is not entirely comparable with the projected earthquake warning pattern. Earthquake warning times will be longer, there will be no natural signs by which people can confirm the imminent danger through their own senses, earthquakes of destructive magnitude occur less frequently, and false alarms can be more costly because of the long period of advance warning. Accordingly, we look to experience with long-term disaster-preparedness and slowly developing social problems for further clues to earthquake prediction response.

(2) Analogies to the long period of advance warning for earthquakes may be found in efforts to achieve long-term disaster-preparedness. The relatively successful efforts have occurred in coal-mining communities where the danger is ever-present and in areas frequently affected by floods and hurricanes. In general, however, well organized and effective long-term preparations for disaster are exceptional. Surveys on the status of both peacetime and wartime disaster preparations have consistently shown that only a small percentage of the population will voluntarily undertake preparation to cope with uncertain future disasters. Even in a community like Crescent City, California, which experienced a disastrous tsunami in 1964, little long-term emergency planning for similar future disasters has been undertaken (Anderson, 1970).

With reference to earthquakes, such long-term hazard-reduction programs as land-use planning and building regulations designed to protect against seismic disturbance are infrequent outside of California and Alaska. Even in high-risk areas of California and Alaska, many communities have failed to adopt or enforce adequate regulations of this sort, and little has been done about structures built before such regulations took effect. Building codes mean added costs for enforcement to owners and the government. Condemnation of old buildings breaks up neighborhoods, creates relocation

problems, and can enhance conflict between special-interest groups (White and Haas, 1975). It is difficult to secure agreement and cooperation among owners, engineers, architects, builders, lending institutions, insurance companies, and government officials. Groups advocating disaster preparedness compete with others who want limited national and local resources used for more immediate, imperative, or well-defined social and interest-group needs. In case of an earthquake prediction, there is real danger that preoccupation with immediate and pressing social and personal concerns will block efforts to capitalize on the long period of advance warning in case of a serious earthquake.

(3) The energy crisis, as a slowly developing social problem, supplies another partial analogy to earthquake prediction. A carefully considered prediction of declining oil production in the United States after ten to fifteen years was issued as early as 1956. The petroleum industry first reacted to the prediction with dismay and disbelief and then attempted to disprove it, leaving the public badly confused (Gillette, 1975). Subsequently, various groups sought to draw public attention to the imminent shortage unless wasteful consumption were reduced and alternative energy sources exploited. But it required the Arab boycott seventeen years later to provoke public awareness and vital concern with the energy crisis. Even then, serious attention to the problem was short-lived, though it is difficult to say whether a natural return of public apathy or the failure of national leadership accounted for the decline of interest.

The energy crisis raises questions about the length of time required to draw adequate attention to the earthquake hazard and about sustaining the awareness once it is developed. The analogy also suggests that some large business organizations that fear financial reverses during an interval between prediction and quake may hire their own seismologists to dispute the evidence on which the prediction is based or the assessment of danger upon which a warning is based.

The lesson from this review of partially analogous situations is that resistances and constraints must be faced squarely by federal, state, and local officials charged with developing earthquake warning systems.

Issuing and Authenticating Predictions

The earthquake prediction and warning process may be viewed as comprised of four basic functions: (1) developing and releasing the prediction; (2) evaluating the technical merit of the prediction; (3) judging appropriate response to prediction; and (4) disseminating the warning. Drawing upon the foregoing discussion of expected responses to predictions and warnings and upon experience with hurricane and tornado warning systems, we shall briefly suggest how each of these functions might be handled.

First, detection of premonitory signs that may lead to earthquake predictions can occur in federal installations, universities. and private research institutions. Scientists identifying these signs will experience conflicting incentives, toward early publication of predictions, and toward delay in releasing the information. The principal pressure against both premature release and undue delay or suppression is peer pressure within the scientific community. Several decades hence, when scientific advance and practical experience have produced a near consensus in the scientific community, we may wish to consider the desirability of establishing one central agency through which most predictions might be issued, coupled with appropriate warnings. But given the currently limited understanding and agreement among seismologists and incomplete instrumentation and base line data, we cannot now justify restricting the issuance of earthquake predictions to a single source, either public or private. Neither is it practical to delay informational releases until scientific consensus is reached. Because of the

great public interest in the prospect of a serious earthquake, it is doubtful that information leaks could be prevented by any means. Furthermore, efforts to restrict public release of predictions would inevitably stifle exchange of information among scientists, which in turn would retard progress in testing competing theories and generating new insights about earthquake prediction.

The most constructive policy is therefore one that encourages prompt release to the public of information that, in the judgment of the scientists concerned, warrants prediction of an earthquake or revision of an earlier prediction. Predictions should flow freely from a variety of scientific sources, in accordance with the scientific freedom enjoyed in this country.

The second function, evaluating the technical merit of the prediction, must also be performed by scientists rather than public officials. The most searching and authentic evaluation will take place through the usual media for academic discourse. But the public official who must decide when to issue a warning and what measures to initiate needs a recognized body of scientists to whom to turn for a prompt, balanced, and unassailable evaluation of any prediction of a potentially destructive quake. Few states have the scientific personnel needed for such a panel, and greatest credibility will be accorded a nationally based group, relatively detached from local and regional political scenes. Hence, the federal government should constitute such a panel now and establish its mode of operation in advance of the first significant prediction.

Issuing Warnings

The third function, determining the appropriate response, must ultimately be the responsibility of local and state officials and leaders in the private sector. However, the federal government is more favorably placed for accumulating experience with earthquakes and predictions under diverse circumstances and for developing technical advisory services. State and local leaders will retain the responsibility for initiating action when a prediction is at hand and for adapting model responses to the local situation. They should develop plans suited to local needs well in advance of the first prediction, while drawing liberally upon the resources of the federal government.

The fourth function, disseminating a warning, will be a momentous step for the public official, who now assumes responsibility for orchestrating a constructive response. The most important immediate concern is that prompt issuance of a warning, including assessment of risk, information concerning community plans, and advice for individual action, not be hindered by uncertainty over the locus of authority. The threatened area will certainly overlap local jurisdictions and sometimes include more than one state. Hence, it is important that the federal government initiate discussion with representatives of governors in potentially affected states to establish responsibilities and procedures for the issuance of warnings. Although the elaborate hierarchy of outlooks, advisories, bulletins, and watches employed for hurricane and tornado warnings may not be useful because of the infrequency of significant earthquakes, comparable terminology should be employed when it is applicable.

The development of a coherent earthquake prediction and warning system will require cooperation among scientists, public officials, and the communication media to provide understandable and unsensational interpretations of reported predictions. A continuing informational program is needed to ensure that public officials and citizens learn directly from scientists the nature of their thinking about earthquake mechanisms and prediction. Public officials, the media, and the general public will require the advice of a disinterested group of scientists in distinguishing valid from doubtful predictions. Cooperation of the communication media will be important in helping people to visualize concretely the laboratories, the

seismographic networks, and the panoply of instruments and devices through which predictions are developed. Outlining concrete response plans should help to add a sense of reality to the warnings as well as to forestall some disorganized and disruptive responses. The development of constructive ways in which citizens and groups can participate actively in preparedness programs should also help to bolster public credence. Emergency plans should provide for activation of citizen involvement directly upon issuance of a warning, with intensified and broadened involvement as the predicted time approaches.

THE CONTEXTS OF RESPONSE TO EARTHQUAKE PREDICTION

Economic Implications of Prediction [2]

Our review of evidence concerning public response to warnings of disaster has shown rather convincingly that the fear of mass panic is unjustified and that the crucial problems will lie in overcoming disbelief and inaction. Even though the popular reaction is the obvious place to start our investigation, the response of economic institutions to the prediction and warning may have more far reaching effects on the community. Will there be large-scale economic disruption because of the prediction? How will land markets and financial markets react? How will economic decision-makers process the information?

In the absence of comparable experience, predicting the economic response will probably be more difficult than predicting the popular response. Decisions affecting the economy will be made in private businesses, public agencies, and households, and by decision-makers within the affected community and in remote parts of the nation and the world. Each set of decisions will affect all others according to complex and ill-defined patterns, ranging from a possible domino effect to more complicated patterns of counter-response and offsetting-opportunity response. Panel members were unable to locate empirical models of sufficient precision and richness to describe these interactions confidently.

The simpler problem of individual economic decision-making under conditions of uncertainty focuses our attention on the probabilistic character of the earthquake event, the probabilistic assessment of the prediction, and a probabilistic assessment of the payoffs for various adjustment mechanisms. Most economic decision-making models assume that individuals seek to maximize expected gains and minimize expected losses, after adjusting the value of gains and losses by the probability of their occurrence. Reasonable as such models are, they may supply a poor guide to economic response to earthquake prediction for at least two reasons. First, none of the probabilities can be specified with much precision. Until we have had experience with a few predictions of significant earthquakes, we are nearer to guessing than to "estimating probabilities." Second, empirical studies of response to uncertainty suggest that decision-makers usually employ highly simplified models of the real world. The most frequent goal of popular economic decision making is to attain an adaptive level of outcome rather than to maximize gains. Research on economic response to natural hazards suggests that potential gains and losses may be disregarded unless a very high probability is initially assigned to the predicted event (Slovic et al., 1974).

Parallel to the fear of panic flight reactions by the populace is a common fear of panic reactions in the economic sphere with resultant disruption of the economy. We cannot be certain how likely these responses are to occur. But all previous experience with regional reactions to bad news tends to support the view that the economy would not be thrown into panic. Attempts to suppress information regarding the prediction could well generate rumors and lead to excessively speculative behavior. An open information policy to keep the public informed

about a possible impending disaster should minimize damaging speculation. In contrast to panic, however, some rational downward adjustment of real estate and financial markets in anticipation of future losses should be expected. Future losses might be lessened by reducing levels of employment, production, and investment within a geographical area judged extremely hazardous; and vulnerable activities might be transferred to other parts of the region or nation. Some economic loss and economic disruption are inevitable. Public assistance for relocating vulnerable activities, aid for reinforcing structures, financial support for public utilities and local governments, a program of federal earthquake insurance, and increased unemployment insurance would do a great deal to stabilize the economy and speed the adjustment process. Federal aid given prior to an earthquake to lessen the negative economic consequences of earthquake warnings may be less costly than traditional post-disaster relief and rehabilitation. But with the advent of long periods of advance warning, the affected region can and should bear much of the cost of adjustment. In order to avoid creating incentives for businesses and residents to remain in hazardous areas without taking steps to reduce risk, grants of aid should be linked to concomitant measures for reducing risks, such as strengthening buildings and removing parapets and other dangerous parts of buildings.

Since the greatest economic gains and losses from earthquake prediction occur in the private sector, it is important to anticipate how different types of businesses can be affected. Reactions of banks, lending institutions, and insurance companies are certain to have a multiplier effect on the local economy. But their reactions will be influenced by federal insurance and aid policies. Standby federal pre-disaster policies to cushion the potential impact of a sudden tightening of credit would probably be desirable. If public pre-disaster policies are established and known in advance, economic reactions within the region should be considerably milder than if there is no published pre-disaster policy at the time the prediction is issued.

Where probabilities of loss are high, securities and real estate markets will probably register declines very quickly. By contrast, small firms and households may wait for more information and not take action until strong public action is evident or until they are affected by the decisions of large-scale firms and financial institutions. Income and employment multiplier effects of the first reactions to the prediction may take several months to result in reduction of personal income and a rise in regional unemployment.

Businesses whose sales are tied to the level of local income and employment may be harder hit than industries whose sales are primarily outside the region. A tendency to postpone durable investments subject to possible damage will be strong. New housing starts and business construction will probably decline and remain down until after the expected quake. Partially offsetting these tendencies will be a demand to strengthen many types of structures and to build up some kinds of inventories. The strength of these demands will depend upon the availability of funds in the money market as a whole and the financial reserve positions of firms and households.

As a tool for hazard mitigation in case of earthquakes, insurance has both its advocates and its detractors. Compulsory disaster insurance, covering all hazards including earthquakes, could distribute costs in both space and time and cushion many of the economic reverses anticipated as a result of an earthquake prediction. Variable premium rates could be used as incentives for increasing the seismic resistance of existing structures. Federal subsidy for insurance could be justified as taking the place of some of the massive federal expenditures that normally follow a disastrous quake. However, existing federally subsidized disaster insurance and privately offered earthquake insurance have been in low demand, and there

are considered doubts concerning the political acceptability, the practical effectiveness, and the feasibility of this comprehensive approach to the economic problems of earthquake prediction through insurance.

Current policies for property insurance are based on the law of large numbers and the pooling of reserves, and are well suited to events such as building fires that occur sporadically and independently. Damages in case of earthquakes are interdependent, however, and there is a problem of adverse risk selection for an entire region. Prediction of a serious quake in a specific region may serve to make clear that reserves based on the law of large numbers could be inadequate to cover anticipated losses. Even with very little earthquake coverage in force, this may apply to fire and extended-coverage insurance. Insurance companies could hardly afford to sell new coverage in the affected area once a prediction was issued, and would experience considerable financial incentive to cancel existing coverage whenever possible. Insurance companies having the legal right to refuse renewal of policies on commercial and residential structures after an earthquake prediction has been issued would find it costly to do so on political and public relations grounds. Without new customers, and with rate increases unlikely to be granted, insurance companies could well find themselves in difficulty after an earthquake prediction. These considerations raise further the question of whether current insurance practices should be thoroughly reexamined in light of the new prospect of an extended period of predicted hazard before the quake occurs.

If local property values fall and if the economy dips following a prediction, property- and sales-tax revenues that account for more than two-thirds of local public revenues will decline. Maintaining schools and other public services will be difficult. If tax incentives are employed to encourage local property owners to reinforce structures, even further losses may be encountered. Public utilities will incur new costs for investment in hazard reduction while their revenues decline. A comprehensive disaster policy is needed both to specify the types of federal aid that will be available in the predisaster period and to determine to what extent taxpayers in other regions should be liable for hazard-reduction in earthquake-prone regions.

Thus far we have been talking of the prediction and warning as public knowledge, available to all. Private foreknowledge (inside information) can lead to redistributive gains and losses without any net benefit to the community (Hirshleifer, 1971). If predictions are prematurely released to insiders, if diffusion of information is imperfect, if some groups can buy superior information through private predictions, then speculators will be in a position to gain at the expense of others through market transactions. If we are to minimize socially undesirable inequities in the distribution of income, it is essential that we insure the prompt release and effective dissemination of all predictive information and warnings as they become available. Thus economic considerations reinforce our earlier conclusion concerning the dangers of delay in releasing predictions.

An important contribution economists can make to our ability to exploit earthquake prediction capability in the public interest will be to conduct comprehensive benefit/cost studies of the various proposed measures for reducing the earthquake hazard. Current procedures for loss estimation have serious economic deficiencies, and refinements are urgently required before useful benefit/cost analyses can be completed.

Legal Implications [3]

The production and issuance of earthquake predictions and warnings and the development and implementation of plans for responding to the predictions take place within a legal system that defines responsibilities and liabilities, and that permits certain actions and prohibits others. A program of hazard mitigation that sub-

jects scientists, public officials, or others to intolerable legal risk will fail, regardless of how well conceived it may be in other respects. Likewise, a program that is well conceived by social, economic, and engineering criteria may be infeasible because of the legal obstacles to its execution. It is essential to understand these legal constraints so as to devise programs that minimize them, or to seek new legislation that will facilitate otherwise infeasible programs.

As part of the Panel report we have recounted legal opinions in answer to several of the most pressing questions surrounding earthquake prediction. The opinions, however, are quite tentative because of the lack of adequate precedent. Furthermore, each answer is hedged about with a set of restricting assumptions concerning the circumstances in which the opinion applies. Consequently it has seemed wise in this presentation merely to identify the questions explored and the main drift of the answers.

Scientists and public officials who release predictions or issue warnings that turn out to be false alarms or erroneous in some significant respect are concerned over whether they incur liability to those who suffer damage or injury because of the prediction or warning. In most cases the publication of such notices should not create liability, provided the announcements are conscientiously issued, based on adequate evidence, and appropriately couched as fallible judgments rather than established facts. On the other hand, if a prediction or warning is withheld for fear of public harm, the possibility of incurring liability in case the quake occurs may be substantial.

In the abstract, land use control powers are among the most promising tools for minimizing death and destruction in a predicted quake. But the immediately practical question is how far individual property rights and other legal constraints stand in the way of implementing land use controls or an emergency basis. When land use controls have the effect of denying a property owner the right to use his property in the usual manner, to what extent must the property owner be compensated for any loss? If a survey of existing buildings is necessary in order to determine what modifications are required, with what success might property owners block or delay entry of inspectors onto their property? What authority is there to enforce modifications in structures built prior to the enactment of recently upgraded building codes? What authority is there to compel property owners to discontinue use of a vulnerable structure for specific purposes, such as a meeting place or a residence? Without attempting to answer these questions, we note that the first few efforts to implement a hazard reduction program based on an earthquake prediction are likely to encounter a series of challenges in the courts, which in total will probably consume several years in litigation. There may very well be insufficient time to overcome each of the obstacles so as to make optional use of hazard reduction measures involving land use control and building code implementation before the quake occurs. Accordingly, it is important to seek appropriate legislation now and make legal preparation at the local, state, and federal levels in advance of the first prediction.

Several other significant questions have been raised. What legal powers are there by which government might offset the dampening effect on the community of a constricting mortgage market? Could and would a credible earthquake prediction be interpreted as an "emergency" under provisions of the Disaster Relief Act of 1974, thereby making disaster assistance available to communities affected by the prediction? It appears unlikely that certain answers can be given, suggesting that clarifying legislation should be enacted.

The Problem of Equity

Disasters affect different population segments unequally, and so do the predictions and the hazard-reduction measures which are set in motion following the prediction. In our justifiable preoccupation with fostering the general

community welfare we can easily overlook the inevitable inequities.

Dangers of death and injury from an earthquake are greatest for people who live in substandard buildings that are structurally weak or vulnerable to fire. These are likely to be older buildings, disproportionately inhabited by the poor, the elderly, and members of minority groups. These population segments are also least likely to possess the personal resources needed to protect themselves in advance from the earthquake hazard, or the political and economic clout necessary to induce landlords and public agencies to implement hazard reducing measures in their behalf. These and other groups who live relatively isolated lives are also least likely to receive warnings promptly when they are issued or to have access to resources and to people who can help them determine just what the warning means for them.

After a disaster has struck, the nature of damage and injury is generally evident to those most directly affected. But the risks to which people are subjected as a result of an earthquake *prediction* – such as economic loss – will not be readily apparent at first. People will not automatically recognize their interests in the face of complex economic, legal, and political maneuvering and unpredictable public responses. The advantage will lie with those who are already represented by well-organized interest groups, which have the resources to examine the situation in depth and ascertain the groups' interests. Small property owners, tenants, and employees in non-union establishments are among those unrepresented groups who are unlikely to recognize potential threats to their interests until it is too late to take protective action.

In most natural disasters the brutal impact on the victims is partially offset by the rise of an unusual spirit of altruism in the community (Barton, 1969; Dynes, 1974). For some people with minimal resources, who are closely tied to the local community by economic necessity or sentiment, the *prediction* of an earthquake may be a disaster. Their losses appear more like an intensification of normal hazards of life than the consequence of a dramatic catastrophic event. As an *invisible catastrophe*, a prediction that precipitates public and organizational responses which ultimately destroy the economic well-being or life style of a population segment is unlikely to evoke a sudden altruistic outpouring among the less affected. Because the prediction, the warning, and the public and private responses are all human actions, the clear mandate of sympathy for the victims of natural catastrophe is muted by confusion over responsibility and blame.

Even the most constructive hazard-reducing steps that can be taken in response to an earthquake warning may hurt some of the people while helping others. For example, it would be sensible in response to a long-term prediction to set stricter building standards in the threatened area and to insist on strengthening and fireproofing many existing structures. But if all or part of the expense is borne by the property owner, directly, or indirectly through increased assessments, the increased costs will drive still more of the economically less well-endowed populations out of the market for conventional housing. Furthermore, the long record of special influence and unevenness in the implementation of land use planning and enforcement of building codes is not likely to be reversed overnight.

No set of rules will automatically insure that the interests of the politically and economically weak and the socially isolated are given adequate attention. It is essential that some public agency be assigned responsibility to serve as watchdog in this regard. Non-governmental community groups will have an important role to play in identifying actual and potential inequities and devising programs for dealing with them constructively.

Political Implications

Political officials will ultimately have to re-

solve the many uncertainties of earthquake prediction to the best of their abilities and exercise leadership in dealing with them. It is important to understand some of the ways in which the political process can affect the making and implementing of decisions, so as to judge how constructive government action can be facilitated.

Mitigation of earthquake hazards has been a lively regional political issue directly after damaging quakes, but interest flags soon after the crisis. Experience suggests that significant advances in earthquake hazard reduction can be achieved if well-conceived legislation and administrative regulations are introduced in the favorable political climate immediately after an earthquake disaster and if authority for implementation is vested in strong and independent government agencies. But will the same conclusion apply to the earthquake *prediction* or *warning*?

The effect of a prediction on the political process may be quite similar to the effect of an actual earthquake when the prediction is given credence in the scientific community and there is only a short interval of days or weeks before the anticipated event. If well-conceived pre-prediction plans are already at hand at local, state, and national levels, capable leaders may win support for what otherwise might be quite extraordinary programs. Without pre-prediction planning, however, frustrated public demands for immediate and comprehensive action may well contribute to community conflict and precipitate ill-considered government action. When the predicted lead time for the quake is longer and the probability of error is substantial, any initial consensus regarding standard emergency preparedness measures may soon dissipate. Without strong and consistent leadership, interest group conflicts over hazard reduction measures and interagency conflict over responsibilities might bring constructive efforts to a standstill.

Issuance of any earthquake prediction bearing the seal of scientific authenticity will subject public officials to immediate demands for clarification and action, with the mass communications media vigorously relaying the demands. Even with a moderately high-probability short-term prediction, political leaders may be tempted to delay issuing warnings because of the need for coordination among several affected political jurisdictions, the common fear of panic we have discussed earlier, and a fear of lessened credibility in case of a false alarm. When the lead time is longer, and especially when the prediction time-window is a long period, a concern over potentially damaging effects of the warning on the local economy will add to the pressure for delay in issuing any warning. Testimony before the Joint Committee on Seismic Safety of the California Legislature on December 13, 1974, and letters from California public officials to the Panel sound a recurring theme, that warnings should not be issued, or that predictions should be suppressed, until there is virtually complete certainty concerning the predicted event. While the public official's own concerns and pressures from some segments of the business community may cause delay in issuing a warning, political and community pressure from other sources will ultimately force the official to issue a warning. But the consequences of delay and of issuing the warning only in response to public pressure will likely be a residue of bitterness and distrust and a lowering of the reservoir of initial support for difficult actions.

After the warning is issued, public officials will encounter quite different degrees of public understanding and appreciation for the three major tasks confronting them. Preparation for post-disaster emergency response will be readily understood and universally applauded. The public will readily appreciate the need to devise hazard reduction plans, but will often be less sanguine about specific measures and the potentially great costs involved. The need to cope with potentially counterproductive responses to the prediction may come as a complete surprise to many people, and there may be little under-

standing or enthusiasm for such programs until the deleterious consequences have been deeply and widely felt on a personal basis.

Public officials can capitalize on the general appreciation of emergency preparedness by organizing opportunities for widespread citizen involvement in preparing for the quake. Participation in emergency preparedness can be made the occasion for educating a wide spectrum of citizens to the practical measures for hazard reduction such as accelerated land use planning, stricter enforcement of building codes, and selective reinforcement and demolition of dangerous structures. Although efforts to anticipate and forestall counterproductive developments may attract little support, citizen groups may be quick to blame local officials if business and employment decline. Hence, it will be important for officials to seek guidance from a respected body of technical advisers and to filter proposals through a larger citizens' group. If these are acting rather than delaying bodies, they should help transfer the difficult decisions out of the realm of political controversy and make some contribution to public confidence.

Although an earthquake prediction pinpoints a localized problem, local and even regional resources will be inadequate to finance an adequate program, as we have indicated in discussing economic aspects. It will not be easy to secure federal assistance on a large scale prior to an actual earthquake. Support for relief in connection with annual hurricane, tornado, and flood threats in other regions may be an effective trade-off in political log-rolling. The federal approach to new problems has been described as typically *incrementalist*, i.e., extending and adapting old programs to new situations rather than devising wholly new approaches (Lowi, 1969; Braybrooke and Lindblom, 1963; Wildavsky, 1964). Accordingly, the most promising approach to securing federal aid should be through seeking modifications of existing federal disaster insurance programs, guaranteed low cost loans for construction, extended periods of eligibility for unemployment insurance, and similar programs.

While evacuation is a familiar approach to many disasters, large scale evacuation in response to earthquake prediction will usually be politically unacceptable, as well as impractical in other respects. Experience with tsunamis and other threats indicates an uncertain public response to government-ordered evacuation of limited areas and vacating of designated structures. When danger is imminent and obvious, as it was in the area below the Van Norman Dam following the San Fernando earthquake of 1971, general compliance with an evacuation order can sometimes be achieved with little difficulty. But with a long lead time, no visible threat, and acknowledged uncertainty over the prediction and the quake's effects, and the possibility that evacuation might last for weeks or months, evacuation plans will become politically quite controversial.

Steps will have to be taken to deal with existing unsafe structures, but conflict will certainly develop over the "taking" of private property and the dispossession of people. Officials must formulate plans with several potent political considerations in mind. First, there must be a sense of active preparation for the quake rather than passive waiting. For example, it is better when possible to demolish unsafe structures rather than to leave them vacated as a blight on the community and an invitation to squatters. Second, work on upgrading and demolishing unsafe structures should be carefully scheduled so as to take up some of the anticipated slack in new construction activity between prediction and quake. Third, considerable thought must be given to minimizing the minor irritants (such as charges for inspection imposed on small property owners) that can easily accumulate, creating an escalating resentment and undermining the disposition to cooperate in community-wide programs of hazard reduction. Fourth, public officials must anticipate and deal constructively with a disposition among the poor and minority groups – who disproportionately inhabit substandard housing – to take a cynical

view of strict building code enforcement and plans to relocate inhabitants from unsafe to safer locations. Long experience has taught them that building codes often have more to do with protecting the building industry and trade unions than with safety for building inhabitants, and that urban redevelopment is often a device to remove the poor to make room for a wealthier or socially more acceptable class of tenants. Furthermore, in many instances the social, psychological, and historical ties to a neighborhood will override definitions of self interest in terms of economics or safety. Fifth, in order not to fall into the trap of rebuilding the community in accordance with an obsolete plan, public officials should develop fresh plans to guide rebuilding and relocation of facilities during both the post-prediction and post-quake periods. And sixth, because the threatened area will usually transcend civil boundaries, and because there will be changes in office holders during the course of long-term predictions, program continuity will depend upon bringing into the planning process both intragovernmental agencies (such as building and planning departments) and interjurisdictional organizations (such as the Association of Bay Area Governments in California).

Both the practical and political obstacles to developing and implementing an effective response to earthquake prediction will be especially great in areas such as the eastern seaboard and Missouri Valley, where the risk of a serious earthquake appears to be substantial but popular and governmental awareness of the risk is low. However, with few structures in these regions designed to be quake-resistant, the potential saving of lives as a result of a program to get people safely away from most buildings at the time of the quake could also be much greater than we anticipate in California where many structures will withstand most earthquakes.

CONCLUSIONS AND RECOMMENDATIONS [4]

From the many recommendations scattered throughout the Report, the Panel selected a few to be highlighted as major recommendations. These recommendations will be presented, along with a brief statement of the associated conclusions whenever they are not quite obvious from earlier discussion in this article. In a separate chapter, the Panel also enumerated a series of specific measures that might be employed as part of a constructive response to the prediction. The most significant of these will be mentioned in connection with the relevant major recommendation.

Prediction in Earthquake Hazard Mitigation

The prospects for saving lives on the basis of an earthquake prediction are much clearer at this time than the prospects for substantial reduction in property loss. In years to come, as experience enables us to establish legal precedents and legislation to facilitate prompt and effective action, and as uncertainties of economic response are resolved, the savings of property and income compared with the costs of an unpredicted quake may be substantial. But for the first prediction of a potentially destructive earthquake it is difficult to estimate the ratio of savings to costs. Under the worst combination of an inaccurate prediction and an ill-conceived public response, the prediction and quake together might even be more costly than an unpredicted quake would have been. By contrast, we know that lives can be saved if we make sure that people are located at safe distances from vulnerable buildings and other structures and are also protected against such derivative dangers as fire when the quake occurs. We know, too, that the saving in lives may in some instances number in the thousands. Because of the real danger that preoccupation with immediate economic costs could prevent people from undertaking and supporting programs that might save thousands of lives, the Panel offered its first recommendation:

Recommendation 1

The highest priority in responding to earthquake prediction should be assigned to saving lives, with secondary attention to minimizing social and economic disruption and property loss, provided the costs are within the limits that society is willing to accept.

Both the consequences of most specific measures and the practical possibilities for putting them into effect are quite uncertain at present. Much will depend upon: (a) private-sector decisions by national business leaders; (b) whether legislation and laws facilitate or impede constructive response; and (c) the stability of the political base for local public officials. Hence, any effort to follow a rigidly prescribed plan for responding to earthquake warning will surely lead the community into a deepening morass of problems. The more effective approach will be to work from a catalogue of specific measures, applied selectively and flexibly according to the local situation, with careful monitoring for effectiveness and for changing conditions.

The more people live, work, study, and play in earthquake-resistant structures, and the more consistently community planners and other public and private officials have taken prior account of earthquake danger, the more manageable will be the tasks to be undertaken when a quake is predicted. As the Panel examined recommended measures to be taken in response to a prediction, it was constantly reminded that a constructive program for utilizing earthquake prediction builds on and supplements a long-term program of planning for earthquakes. Accordingly, the Panel recommends:

Recommendation 2

Prediction should be used in conjunction with a complete program of earthquake-hazard reduction, and not as a substitute for any of the procedures in current use.

Because of the infrequency of earthquakes of destructive magnitude within any one locality in the United States, an agency established exclusively to cope with earthquake predictions would surely stagnate and suffer reduced funding during intervals between serious quakes. Because of anticipated long periods of advance warning, many of the tasks of responding to earthquake predictions will fall within the province of departments of planning, building and safety, and engineering and public works, rather than the police, civil defense units, and other agencies most concerned with emergency mobilization. Consequently, the Panel recommends a substantial reorientation of thinking and authority for coordinating response to earthquake warnings as compared with other disaster warnings:

Recommendation 3

The primary responsibility for planning and responding to earthquake predictions should be assigned to federal, state, local, and private agencies having broad concern for community and economic planning and for disaster preparedness and response, rather than to newly formed agencies established especially to deal with earthquake prediction and warning, or to agencies concerned primarily with emergency response.

If we are to make constructive use of the prediction capability, we shall need advance clarification of the many legal uncertainties that have already been discussed. In particular we shall need to insure that existing federal disaster relief provisions can be applied immediately when an earthquake warning is issued. The Panel made two recommendations:

Recommendation 4

As an essential feature of advance planning, legal determinations and clarifying legislation should be sought to minimize the legal ambi-

guities that otherwise will hamper officials in making constructive response to earthquake prediction.

Recommendation 5

Legal inquiry should be undertaken to clarify what powers for responding to earthquake predictions now exist under the Disaster Relief Act of 1974 (PL 93-288), and what further powers might be necessary. Any deficiency or uncertainty regarding application to the emergency created by prediction of a potentially destructive earthquake should be promptly corrected by new legislation.

In response to the pervasive problem of equity, the Panel recommends:

Recommendation 6

A public agency should be assigned the responsibility to (a) identify groups of people most likely to need special assistance in the event of an earthquake or to suffer disproportionate loss and disruption when an earthquake is predicted, (b) develop a plan to offset, insofar as is practicable, the inequitable costs and suffering attendant on both the quake and the prediction, (c) monitor events after the prediction from the point of view of equity, and (d) help unorganized population segments to recognize how the earthquake prediction affects their interests.

Some of the urgent questions that will require intensive and continuing investigation are identified in a series of recommendations for research.

Research recommendation 1

High priority should be assigned to developing a standby anticipatory research capability to be utilized as future earthquake predictions are issued. The plan should include comprehensive examination of the social, economic, legal, and political effects of the prediction and of the actual quake.

Research recommendation 2

Socioeconomic monitoring should be established concurrently with geophysical monitoring in order to develop baseline data and methodology, to serve as a standard for measuring the social, political, and economic impact of earthquake prediction, and to refine techniques that can be applied to other regions as the geophysical monitoring networks are expanded.

Research recommendation 3

Continuing investigation should be made of experiences in utilizing earthquake prediction in countries such as Japan, the Soviet Union, and China, and of the effects of introducing prediction technology in other countries such as developing nations where earthquake risk is high.

Research recommendation 4

A comprehensive study should be launched on the legal problems likely to be encountered as earthquake-prediction capabilities develop. Preparation of a compendium of federal and state laws pertaining to earthquake prediction and earthquake-mitigation measures would be a useful beginning.

Research recommendation 5

A comprehensive investigation should be conducted on the division of function and responsibility among the various levels of government and the interrelationships among government and private agencies whose efforts must be coordinated in connection with earthquake prediction and hazard mitigation.

Prediction and warning

The discussion of problems in issuing predictions has already sensitized the reader to a variety of dangers for public policy, including the following circumstances: predictions will develop incrementally and be subject to revision, and will not approach certainty within the foreseeable future; many people lack the background to understand predictions stated in probabilistic terms, or to distinguish scientifically authenticated predictions from those with no scientific basis; some groups stand to gain financially at the expense of others if they can secure inside information before a prediction is made known to the general public; many business leaders and public officials will be tempted to call for the suppression of predictions to forestall possible economic and political disruption; predictions that are withheld will almost certainly surface through unofficial channels, leading to public recrimination and distrust that will undermine cooperation in earthquake mitigation programs; delay in releasing predictions will reduce the time available to make orderly use of land use planning and strict building code enforcement to reduce the earthquake hazard. The Panel offered two recommendations:

Recommendation 7

Predictions should be developed, assessed, and issued to the public by scientists rather than by public officials. Procedures must be developed to ensure the free and timely flow of information concerning the prediction to all segments of the public. Legislation may be required to assure that information that an earthquake will occur at a given location and time will not be withheld from general knowledge to the advantage of special interests.

Recommendation 8

A designated federal agency should establish a group of governmental and non-governmental scientists who can be called upon to evaluate specific earthquake predictions. The responsibility for establishing this group should not be vested in any agency that is involved in the technical pursuit of earthquake prediction. This agency should also maintain a record of all published predictions.

While predictions are strictly technical matters, issuing and assessing warnings are peculiarly the responsibility of public officials acting in the interests of the people they represent. Because of the well-documented public disposition toward disbelief and inaction in the face of threatened danger, it is important that official warnings be announced in such fashion as to maximize credibility and readiness to cooperate. Past experience with other types of disaster indicates that public officials often delay issuing warnings with deleterious effects because of mistaken fears of mass panic and of a "crying wolf" effect in case of a false alarm. At present the responsibility for issuing such warnings is dangerously undefined, as among local, state, and federal government levels, and where several local jurisdictions are affected. The Panel concluded that ambiguities must be resolved before the occasion of the first prediction of a potentially destructive earthquake, and offered two recommendations concerning earthquake warnings:

Recommendation 9

A designated federal agency should confer promptly with governors of the principal earthquake-prone states or their representatives to clarify the respective responsibilities at each level of government and to establish procedures for issuing earthquake warnings.

Recommendation 10

A warning should be issued by elected officials promptly after a credible prediction of a potentially destructive earthquake has been

authenticated. A warning should include a frank assessment of the prediction, noting the possibilities for error, information on the types and extent of damage that the earthquake could cause, a statement concerning plans being developed to prepare for the quake, and advice concerning appropriate action to be taken by individuals and organizations.

Warnings are of little value unless they are both received and understood by all segments of the population. Based on changing predictions and on the pattern of public response, warnings must be periodically reviewed, reaffirmed, and revised. The Panel recommends:

Recommendation 11

A designated federal agency should establish mechanisms for monitoring public understanding, credence, and response at all stages of the prediction-warning-earthquake sequence, and for making this information available promptly to responsible public officials.

Recommendation 12

Careful attention should be paid to the problems of communicating to segments of the population that might otherwise only receive last-minute warnings belatedly. These segments include such groups as foreign-speaking minorities, the physically handicapped, tourists, and the socially isolated.

Again, there is much to be known about public reception and understanding of earthquake predictions and warnings that can only be learned by a well considered program of research:

Research recommendation 6

Circumstances influencing the credibility of earthquake predictions and warnings, and techniques for improving their credibility, need more careful study.

Research recommendation 7

Research is needed on how people process information regarding low-probability disasters and how this processing changes when a prediction alters the probability. It is important to gain more understanding of how people establish acceptable levels of risk in such instances.

Research recommendation 8

Popular perceptions and understandings of earthquakes and earthquake prediction should be investigated, comparing populations in different earthquake-prone regions of the United States and among people who have experienced severe quakes, minor quakes, and those who have no previous experience with earthquakes.

Hazard-Reduction Measures

The prospect of substantially reducing the earthquake hazard on the basis of a prediction will be greatest when there is a plan in readiness before a prediction is made and when the plan is part of a continuing program of hazard reduction. The Panel recommends:

Recommendation 13

As part of a complete and continuing earthquake mitigation program, each earthquake-vulnerable community should develop a hazard-reduction program, involving both public and private agencies, to be placed in effect in case of an earthquake warning. A designated federal agency should establish a central clearing house to provide the necessary hazard-reduction information and technical assistance to states, which in turn will aid communities in developing their plans and in implementing them.

Unlike floods, hurricanes, and tornadoes, earthquakes would seldom be lethal were it not for the structures humans build that cannot withstand violent earth movement. Hence, the

principal focus for hazard-reduction strategy is dealing with earthquake-vulnerable structures. With long-term predictions this means emphasis on land-use management and on structural-design and -maintenance programs. In the short term it means vacating dangerous structures and guarding against special hazards such as fire. In any particular situation the period of advance warning, length of the prediction time-window, concentration of population, economic costs, legal constraints, and credence placed in the prediction will all affect the possibilities for action. Responsible public and private leaders will have to determine the most effective combination of measures in each instance. But the Panel agreed that a basic set of measures merited consideration in each case, and made the following recommendation:

Recommendation 14

Each threatened community should examine the applicability of each of the following major kinds of hazard-reduction measures: (a) evacuating limited areas and vacating dangerous structures; (b) accelerating structural-design and -maintenance programs; (c) employing land-use planning and management powers in relation to the predicted locale of the quake; (d) protecting essential natural gas and other community lifelines; (e) dealing with such possible hazards as nuclear plants, vulnerable dams, highly flammable structures and natural cover, and facilities involving the risk of explosion and the release of dangerous chemicals.

More specific illustrations of the steps envisaged under each of these headings will be briefly suggested.

(a) Massive evacuation will rarely be an acceptable strategy because of the crippling effect on the threatened community, the difficulty in locating suitable host communities, the demoralizing consequences of separating family members and removing dependent people from familiar surroundings at a time of stress, and the many direct costs incurred in the evacuation process. But *selective evacuation* and systematic *vacating* of unsafe structures will be essential in dealing with tsunami and landslide hazards, and with unsafe structures and inappropriate land use that remain after all practicable corrective steps have been taken. With one or several years of advance warning, a careful study could be initiated to identify areas and structures where hazards cannot be suitably reduced by other means, and evacuation plans could be developed for these locations. With less than a year of advance warning, evacuation plans could be applied to more obviously dangerous localities, such as areas downstream from potentially unsafe dams, areas susceptible to unmanageable fire, and areas especially vulnerable because of proximity to the predicted point of impact. All of these steps can be executed more effectively if communities begin now to conduct feasibility studies of alternative plans for selective evacuation.

(b) The aim of structural design and maintenance is to insure that all buildings occupied by human beings and structures such as bridges and towers that might collapse on passers-by are built to conform with acceptable standards of earthquake resistance. The special value of an earthquake prediction is to permit accelerated application of these standards within the targeted area. The slow and costly process of bringing all structures up to a reasonable standard of safety can be accelerated within the area of greatest danger. With a year or more of advance warning, a comprehensive program could be launched, to include such steps as the following: building codes can be reassessed in relation to the anticipated magnitude of the quake; critical structures can be identified, their safety assessed, and either brought up to standard or the critical activities relocated; a public agency can be designated to advise owners of noncritical structures concerning the vulnerability of these structures to the predicted quake, and assist them in bringing the structures up to standard or in some cases demolishing them and relocat-

ing the activities; regulations and procedures can be adopted to insure that relatively safe structures are not allowed to deteriorate, and that seismic-risk analyses are required for transfering ownership of certain categories of property in the threatened area. With less than a year's warning, limited strengthening and demolition of vulnerable structures might still be undertaken, and hazardous and valuable materials could be transferred from unsafe structures. Again, communities that start now to accumulate and maintain up-dated information on the seismic resistance of critical structures and to develop contingency plans for responding to any earthquake prediction will be in the most favorable position when an earthquake prediction is issued.

(c) The effectiveness of land-use planning depends upon being able to pinpoint specific zones of relative safety and danger. The earthquake prediction adds significant new information concerning places of greatest risk. When the period of advance warning is long enough, revised planning for hazard reduction is made possible. With a year or more of advance warning, and a favorable political climate, several steps might be taken: detailed earthquake hazard maps, modified to reflect the prediction, can be made generally available; existing land-use plans can be promptly modified, and existing land use reassessed in relation to the new information; special attention can be devoted to removing, replacing, or strengthening vulnerable lifeline elements in high-risk locations; taxation and other powers might be used to encourage desirable modifications in land use; plans should be developed for appropriate land use after the earthquake. With less than a year's warning, existing land-use information or a quick survey could be used to identify relatively safe and dangerous locations. The most constructive response will be possible when communities have already identified earthquake-related land-use problems, when potential problems from lifeline units have been identified at a state level and contingency plans developed, and when federal study of land-use planning and management in areas of high and moderate earthquake risk has created resources for the assistance of local communities.

(d and e) Each community will have unique hazards to deal with. One community will be dependent on an aqueduct for its water supply, one will be bordered by inflammable brush land, and one will house a plant where toxic chemicals are manufactured. Many of these hazards will be under private or state or federal control, so that local officials must depend upon voluntary cooperation. With either long or short periods of warning, a variety of steps can be taken wherever they are appropriate to the local situation: natural gas and petroleum pipe lines and incompressible fluid lines can be shut down; traffic can be diverted from vulnerable bridges and underpasses and vulnerable stretches of subway lines closed; reservoirs can be lowered behind vulnerable dams; firebreaks can be created and other steps taken to lessen fire hazard; protective measures can be taken against pollution hazards such as the rupture of sewage lines; supplies of fuel and hazardous chemicals in storage tanks can be reduced, and operations suspended in potentially dangerous factories and nuclear and hydroelectric power plants; ships can be cleared from harbors where there is a tsunami threat; departures from work can be rescheduled to avoid rush-hour bottleneck traffic. Each community, and all federal and state agencies and public utilities should start now to maintain an inventory of all special potentially hazardous facilities and make plans for dealing with them in case of an earthquake warning.

It should now be clear that an adequate hazard-reduction program will be expensive, though with effective planning the costs should be offset by reduced property loss and economic disruption from the actual quake. The Panel recommended:

Recommendation 15

It should be accepted policy on the part of public and private agencies that a considerable part of the financial assistance normally available to a community after an earthquake should be made available as needed for hazard-reduction measures taken in response to an authenticated prediction of a potentially destructive earthquake. New legislation should be enacted as required to achieve this end, taking into account the example of such existing legislation as PL 93-288, The Disaster Relief Act of 1974, especially Title IV, Section 417 of that Act on "Fire Suppression Grants."

Many of the measures that seem most promising for earthquake hazard-reduction may prove difficult to implement or ineffective because of various social, political, economic, psychological, and legal considerations. The Panel was unable to reach a conclusion concerning the effectiveness of insurance as a way of spreading losses and providing incentives, through rate differentials, for investing in earthquake-resistant construction. Furthermore, assessment of the merits of various hazard-reduction measures depends upon having satisfactory ways to estimate the losses from future earthquakes, and understanding the complex decision-making interactions among public and private organizations and groups. Accordingly, the Panel recommended research into several crucial questions.

Research Recommendation 9

Intensive study is needed on the feasibility of implementing the hazard-reduction measures suggested in Recommendation 13 and on their probable effectiveness.

Research Recommendation 10

A thorough study is needed of the potential role of insurance as an approach to the problem of hazard reduction and of the political and economic implications of alternatives to the current system of voluntary earthquake insurance.

Research Recommendation 11

Research should be conducted on refining the theory and method of estimating losses from future earthquakes and on comparing the benefits and costs of various alternative hazard-reduction measures.

Research Recommendation 12

Several prototype economic models for earthquake-prone regions should be developed for estimating the dynamic interactions among the public sector, businesses, and households, assuming alternative earthquake-warning sequences.

Readying Emergency Services

There is much accumulated experience with emergency planning at local, state and federal levels. But earthquake planning is generally based on the assumption that the quake will occur without advance warning. Both public and private agencies should be able to use the period between warning and quake to prepare their personnel and facilities for the response to the earthquake when it comes. Anticipating the location and magnitude of the quake should be especially helpful to agencies in planning the most effective emergency response.

Recommendation 16

Emergency plans in earthquake-vulnerable areas should be revised to include programs for readying emergency services in the interval between warning and quake.

Emergency response is the phase of earthquake preparation most easily understandable

to the layman and most suitable for large-scale citizen involvement. With careful planning, such involvement can help to upgrade the effectiveness of the community's response when the quake occurs, to enhance the credibility of the prediction by involving people in readily understandable action, and to augment public support for some of the less popular but essential measures in preparing the community for the earthquake.

Recommendation 17

Emergency plans should include programs for broad and active citizen involvement in preparing for the earthquake.

Dealing with Counterproductive Consequences of Prediction

Evidence from other threatening situations suggests that most inhabitants of an area will attempt to continue life as usual, but the foundation of the regional or local economy may be significantly influenced. If mortgages, insurance, and investment are limited in the threatened area and even a small but significant outmigration occurs, rising unemployment, falling property values, and reduced community tax revenue will become problems for the community. The Panel could neither estimate the extent of such possible economic disruption nor specify the precise techniques for dealing with it, but recommended instead:

Recommendation 18

Upon issuance of an earthquake warning a joint governmental and private-sector commission should be established to monitor the economy in the threatened area to ensure early detection of changes, and make recommendations to government, business, and labor organizations as needed. Representatives of insurance and investment organizations should be included and should play an integral part in the work of the commission.

Underlying all policy discussions will be the general question of whether to sustain the community or to allow and encourage an orderly outflow of capital and population. There is danger that mutually contradictory plans may be developed if this issue is not addressed directly and resolved unambiguously.

Recommendation 19

In the event of a credible earthquake prediction, policy-makers must continuously weigh the relative merits of sustaining the economy in the threatened area at its pre-warning level or of encouraging some orderly outflow of capital. Economic subsidies may be required either to sustain the economy or to protect groups of people who would otherwise suffer undue hardship as a consequence of economic dislocation resulting from the prediction and warning.

As services regarding earthquake mitigation are offered to the public by businesses and individuals, steps may be required to protect the public against unscrupulous opportunists.

Recommendation 20

Consideration should be given to the development of standards to govern the practices of businesses and individuals offering services to the public regarding earthquake mitigation.

The need for more information on which public officials can base their actions is especially acute with respect to the economic response.

Research recommendation 13

Research is needed on the probable decisions affecting the economy of the threatened area made by both local and national business and financial leaders and the various economic interactions that are likely to result from these decisions.

Research recommendation 14

The likely effects of earthquake predictions on how various kinds of markets process information and discount changes in the size and timing of losses should be studied in depth. Special attention should be focused on markets for securities (public and private), land markets, financial institutions, insurance practices, metropolitan and local public finance, and problems of financing and maintaining public utility operation.

NOTES

1 This article is a summary of *Earthquake Prediction and Public Policy*, prepared for *Mass Emergencies* by the Chairman of the Panel on Public Policy Implications of Earthquake Prediction, Advisory Committee on Emergency Planning, Commission on Sociotechnical Systems, National Research Council – National Academy of Sciences. Although the summary expresses the author's interpretations and judgments of what is more and less important in the report, it makes liberal use of actual words and sentences from the report. Both the substance and the writing of the Panel's report are the product of collective effort. William A. Anderson, James M. Brown, C. Martin Duke, Charles E. Fritz, Jerome W. Milliman, E.L. Quarantelli, Robert H. Simpson, H.R. Temple, and Ralph H. Turner all wrote portions of the report, and Sarah Osgood Brooks contributed extensive editorial revision. Others whose ideas have been incorporated in the report include J. Eugene Haas, Robert M. Hamilton, Howard C. Kunreuther, James F. Lander, Arnold J. Meltsner, Ugo Morelli, Richard Park, Robert E. Schnabel, Stanley Scott, Karl V. Steinbrugge, Charles C. Thiel, Jr., Robert E. Wallace, Robert Warren, and Alan J. Wyner. Ernst Weber made helpful comments on the draft of this article.

The complete report is available in a 151-page paperbound edition for $6.50 from the Printing and Publishing Office, Dept. JH 726, National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C. 20418. A check or money order must accompany all orders unless a bona fide purchase order is enclosed. Purchase orders of $7.50 or less must be accompanied by a check or money order.

2 The economic analysis of which this section is a summary was uniquely the work of Jerome W. Milliman, who received consultation and advice from Howard Kunreuther and Karl Steinbrugge.

3 The legal analysis in the original report was prepared by James M. Brown.

4 Conclusions and recommendations are uniquely applicable to the situation in the United States and will often require modification to fit the circumstances in other countries.

REFERENCES

Anderson, William A. (1970). "Tsunami Warning in Crescent City, California, and Hilo, Hawaii," *The Great Alaska Earthquake of 1964*, Vol. 7: *Human Ecology*, Committee on the Alaska Earthquake, National Research Council, pp. 116–124. Washington, D.C.: National Academy of Sciences.

Barton, Allen H. (1969). *Communities in Disaster: A Sociological Analysis of Collective Stress Situations*. New York: Anchor Books.

Braybrooke, David, and Charles Lindblom (1963). *A Strategy of Decision*. New York: Free Press.

Dynes, Russell R. (1974). *Organized Behavior in Disaster*. Columbus, Ohio: Ohio State University, Disaster Research Center.

Fritz, Charles E. (1961). "Disaster," in Robert K. Merton and Robert A. Nisbet (eds.), *Contemporary Social Problems*, pp. 651–694. New York: Harcourt, Brace, and World.

Fritz, Charles E., and J.H. Mathewson (1957). *Convergence Behavior in Disasters: A Problem in Social Control*. Washington, D.C.: National Academy of Sciences–National Research Council.

Gillette, Robert (1975). "Oil and gas resources: Academy calls USGS math misleading," *Science* 18 (February 28): 723–727.

Greensfelder, Roger W. (1974), "Progress in earthquake prediction" *California Geology* 27 (August): 188–189.

Haas, J. Eugene (1974), "Forecasting the consequences of earthquake forecasting," *Social Science Perspectives on the Coming San Francisco Earthquake: Economic Impact, Prediction, and Reconstruction*. Natural Hazard Working Paper No. 25. Boulder, Colo.: University of Colorado, Institute of Behavioral Science.

Hirschleifer, Jack (1971). "The private and social value of information and the reward for inventive activity," *American Economic Review* 61: 561–574.

Kisslinger, Karl (1974). "Earthquake Prediction," *Physics Today* 27 (March): 36–42.

Lowi, Theodore J. (1969). *End of Liberalism*. New York: Norton.

McLuckie, Benjamin F. (1973). *The Warning System: A Social Science Perspective*. Washington, D.C.: U.S. Government Printing Office.

Moore, Harry E. (1964). . . . *and the Winds Blew*. Austin: Hogg Foundation for Mental Health, University of Texas Press.

Quarantelli, E.L. and Russell R. Dynes (1972). "When Disaster Strikes: It Isn't Much Like What You've Heard and Read About," *Psychology Today* 5 (February): 66–70.

Scholz, Christopher H., Lynn R. Sykes, and Yash P. Aggarwal (1973), "Earthquake Prediction: A Physical Basis," *Science*, 181 (August 31): 803–810.

Slovic, Paul, Howard Kunreuther and Gilbert F. White (1974). "Decision Processes, Rationality, and Adjustment to Natural Hazards," *Natural Hazards; Local, National, and Global*, Gilbert F. White (ed.), pp. 187–205. New York: Oxford University.

White, Gilbert F. and J. Eugene Haas (1975). *Assessment of Research on Natural Hazards*. Cambridge, Mass.: The MIT Press.

Wildavsky, Aaron (1964). *The Politics of the Budgetary Process*. Boston: Little, Brown and Co.