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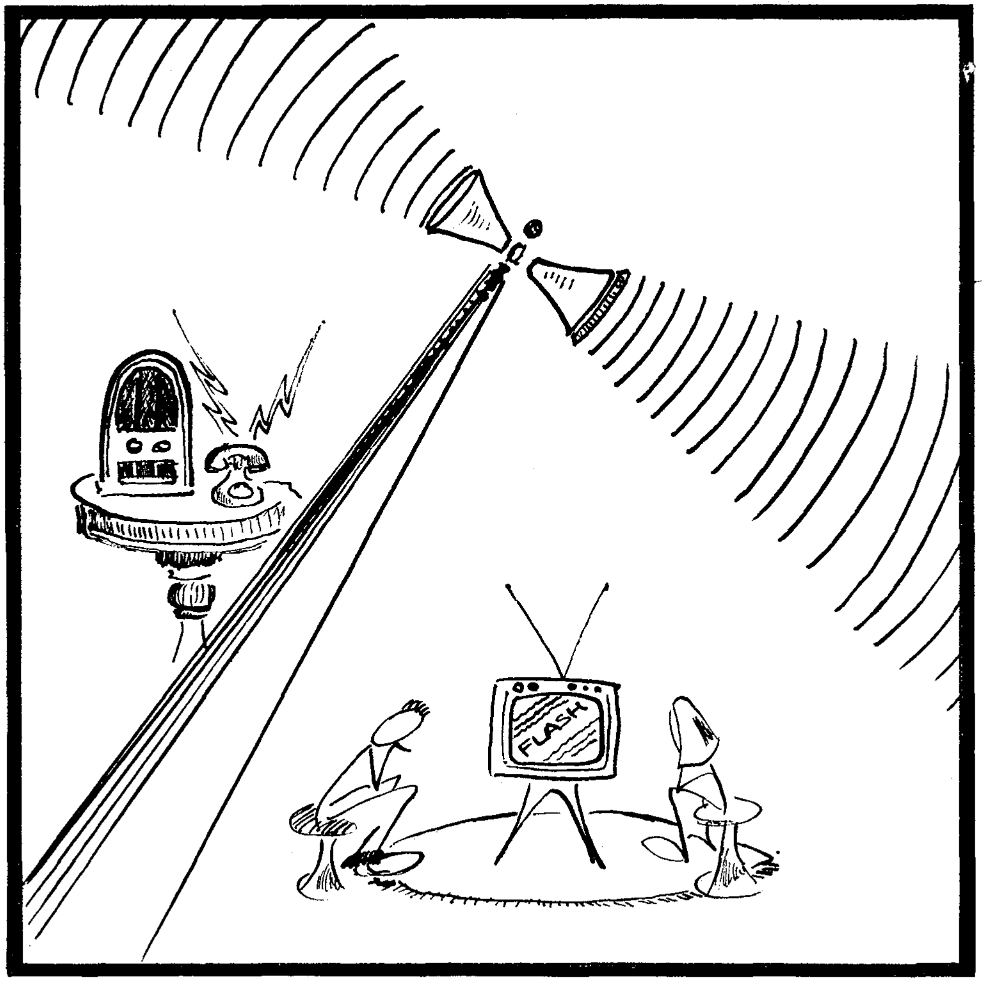
NATURAL HAZARD WARNING SYSTEMS IN THE UNITED STATES: A Research Assessment

Dennis S. Mileti



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IN THE UNITED STATES:
A Research Assessment

Dennis S. Mileti
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Program on Technology, Environment and Man
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Dennis S. Mileti
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ASSESSMENT OF RESEARCH ON NATURAL HAZARDS
AIMS AND METHODS

The Assessment of Research on Natural Hazards is intended to serve two purposes: (1) it provides a more nearly balanced and comprehensive basis for judging the probable social utility of allocation of funds and personnel of various types of research on natural hazards; (2) it stimulates, in the process, a more systematic appraisal of research needs by scientific investigators in cooperation with the users of their findings.

The basic mode of analysis is to examine the complex set of interactions between social systems and natural systems which create hazards from the extreme geophysical events. The chief hazards investigated relate to: coastal erosion, drought, earthquake, flood, frost, hail, hurricane, landslide, lightning, snow avalanche, tornado, tsunami, urban snow, volcano, and windstorms. For each of those hazards the physical characteristics of the extreme events in the natural system are examined. The present use of hazardous areas and the variety of adjustments which people have made to extreme events are reviewed. The range of adjustments includes measures to modify the event, as by seeding a hurricane; modifying the hazard, as by adjusting building or land use to take account of the impact of the extreme event; and distributing the losses, as by insurance or relief. Taking all of the adjustments into account, the impact of the hazard upon society is estimated in terms of property losses, fatalities and injuries, and systemic disruption. An effort is made to identify the directions of change in the mix of adjustments and in their social impact. As a part of this review, those forces in the national society which shape the decisions about adjustments are appraised.

Authorities in the field are consulted through the medium of literature review, workshops on specific hazards, a national conference which was held in October, 1973, and individual reviews. Where appropriate and practicable, simulations of the extreme events and of their social impacts are carried out. In selected areas scenarios of past and possible future events and their consequences are constructed.

In the light of this analysis the possible contributions of research to amelioration of the national condition with respect to each hazard are assessed. Each set of adjustments is reviewed in terms of its potential effects upon national economic efficiency, enhancement of human health, the avoidance of crisis surprise, the equitable distribution of costs, and the preservation of environmental options. Evaluation of particular research activities includes (1) the average sum of social costs and social benefits from application of a given adjustment in changing property use, and (2) reduction in average fatalities and casualties. In addition to the direct impacts of extreme events upon society, account is taken of the costs and benefits which society reaps in seeking to cope with the hazards, as in the case of costs of insurance or of control works.

In addition to calculating the average effects of hazard adjustments, an effort is made to estimate the degree to which the occurrence of a very rare event which has dramatic destructive potentialities, such as an 8.0 earthquake or a 200-year flood, would disrupt society.

Estimates also are made of the extent to which the adoption of an adjustment reduces the options of maintenance of environmental values, and the degree to which the pattern of distribution of income among various groups in society may be changed.

Research proposals are appraised in the light of the likelihood that the research undertaken could yield significant findings, and the likelihood that once the research is completed satisfactorily, the findings may be adopted and practiced by the individuals or public agencies in a position to benefit.

The United States as a whole is doing a competent job of dealing with some aspects of its natural hazards and a very ragged job of handling other aspects. The overall picture is one of rising annual property damage, decreasing loss of life and casualties, coupled with a marked growth in the potentiality for catastrophic events. On the whole, the public costs of adjustments are increasing.

The assessment reveals that very little is known about the dynamic relationships among many of the adjustments. It is difficult to predict with any confidence what the consequence of new Federal investments or initiatives will be in particular adjustments.

For each hazard a set of research opportunities deserving special consideration for early adoption is presented. In addition, three types of research which cut across the various hazards are assessed: warning systems, land management, and relief and rehabilitation.

Among the research basic to other aspects of natural hazards activity are: carefully planned post-audits of certain disasters by interdisciplinary teams; community observations over time of critical points (recovery policies and administration, health, mental health, and preventive measures) of change and of the effects of Federal-state-community interaction; and a clearinghouse service.

In most research fields it is noted that certain types of research which have claimed substantial amounts of public support offer little prospect of effecting a basic change in the character of the national hazard situation. In those instances there are new lines of emphasis which promise larger returns. Many of these involve more explicit collaboration of social scientists and natural scientists than has been customary in past. Wherever appropriate, the research recommendations include explicit provision for the translation of research findings into action by individuals or public groups.

To initiate effectively the desirable new lines of research will in some instances require a readjustment in legislative authority. In other cases it will require an increase in or reallocation of public funds for research. Much of it will involve changes in administrative procedures and policies of the responsible funding agencies. In many instances the effectiveness of the research will be linked strongly with the resolution of issues of public policy. These issues evolve around national land use management, financial assistance to sufferers from disasters, and the sharing of responsibility among local, state, and Federal agencies in designing and maintaining community preparedness.

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SUMMARY

Research leading to new knowledge on hazard warning systems may serve to lessen catastrophe potential, loss of life, and social disruption. Several unanswered questions retard benefits promised by the warning systems which currently cost the nation in excess of $140 million annually for direct operations exclusive of the expenses of people who respond. Why do some people respond adaptively and in time to disaster warnings while others do not? Why can some communities get good warnings to people in danger in time while a large number of locales continue to be plagued by inadequate warnings? What role can research and the application of existing and new knowledge play in upgrading all warning processes to reduce loss from predictable hazards?

Warning systems must be assessed from an integrated perspective, including every stage of the total warning process from the first detection and forecast of a hazard threat through public response. Existing knowledge is not being put to full use in warning preparedness. There are ways of using research to help maximize the potential rewards.

Fields in which new inquiry promises useful results center around 1. the social and psychological factors affecting public warning response; 2. the organizational links in warning systems between the variety of groups and agencies which evaluate threat information and disseminate public warnings; and 3. means of encouraging integrated warning systems as part of preparedness programs.

Relationship to Research on Specific Hazards

Cross-hazard warning research is closely related to the hazard-specific warning research in several ways. Basic warning system processes may be conceptually the same across hazards. A conclusion that the study of a warning system for one hazard would not be worthwhile may not exclude its utility in studying the basic components of warning systems. Research on hailstorm warnings alone would not be justified, but some aspects of possible hail warnings may be quite relevant to a more comprehensive inquiry on warning systems.

Integrated Warning Systems and Dramatic Events

Hazards possess different physical characteristics which have direct implications for warning. Hazards (flood, tornado, wind, tsunami, hurricane, and volcano) which pose a threat to life and property, and require relatively quick response to avert catastrophe are those for which warning systems can avert loss most dramatically. A warning system is composed of more than the sending of a message. An integrated system actively incorporates three basic processes: 1. *evaluation,* the detection, measurement, collation, and interpretation of threat data (typically referred to as prediction and forecast); 2. *dissemination,* the decision to warn, message formulation (when warning is not accomplished by purely technical means such as sirens), and message conveyance; and 3. *response* by those who receive the warnings.

Evaluation begins when there is some indication of an impending impact of geophysical forces, dissemination is based on evaluation, and response is the ultimate purpose of the entire system.

Many hazards are weather-related (avalanches, drought, flood, frost, hail, hurricane, lightning, tornado, urban snow, and wind). Warning for each, despite variations in predictive ability as well as in what might be considered appropriate warning response, begins with similar agencies for environmental monitoring, detection and forecasting. Weather observation systems, interorganizational communication systems, forecasting centers, and public warning-dissemination systems for these hazards vary in level of adequacy. Although all components could be upgraded, public warning-dissemination systems currently are the least adequate.

The Status of Knowledge

Two types of knowledge are relevant to any warning system: technical for forecasting, and scientific for the system's structure, maintenance, and operation.

The National Weather Service (NWS) is responsible for the detection and forecast of floods in the United States except for the Tennessee River Basin, where responsibility is shared with the Tennessee Valley Authority (TVA). Accurate forecasting of precipitation quantities and intensities for specific areas is difficult, and current systems are inadequate for flash flood forecasting.

Prediction and detection for tornadoes and destructive wind is difficult at the present time. The NWS has the principal responsibility.

Tsunami prediction is inhibited by a lack of knowledge of the hazard. The Tsunami Warning System in the Pacific is able to provide estimated times of arrival; more specific forecast data are generally impossible to obtain.

Hurricane forecasting, based in the NWS, is possible, although the technique could be upgraded in prediction of storm movement and other factors. Hurricane watches, advisories, bulletins, and warnings are disseminated through components of the system.

Avalanche prediction is at best only a partially developed technique. An "avalanche hazard rating index" is currently under development. Once completed and used in conjunction with weather forecasts, an avalanche warning service can be established.

Coastal erosion warnings are extensions of the hurricane storm surge and high water warnings issued from NWS forecasting centers along the United States coasts.

Drought prediction is not now feasible. However, the National Oceanic and Atmospheric Administration's Drought Index and the Palmer's Crop Moisture Index are used currently to assess accumulating drought conditions throughout the growing season.

Earthquake prediction and forecasting are still under development. No warning system currently exists, but recent research generates optimism that one could be put into operation by the U.S. Geological Survey (USGS) within a few years.

At present two specialized programs are operated by the NWS for frost forecasting. These are the Fruit-Frost Weather Service and the Agricultural Weather Service. The services do not exist for all portions of the country subject to the hazard; frost forecast is incorporated only into general weather forecast services in those areas.

The forecast of thunderstorms "probably with hail" can often be given as much as 24 hours in advance; however, such forecasts are for large geographical areas, and the actual hailstorm is of small areal extent. Individual hailswaths and hail intensities cannot be forecast presently with any demonstrable skill.

General landslide predictions based on seasonal considerations are possible in some areas of the country. More nearly precise forecasts are not possible at this time.

The NWS, at its Severe Local Storm Forecast Center at Kansas City, is capable of detecting potentially hazardous lightning storms. In conjunction with more general forecasts, the Forest Service can determine fire conditions, the principal danger posed by lightning.

Snowfall forecasts also are made by NWS, and there is disagreement on whether accuracy is improving. In terms of upgrading snow warning response, improvements in snow prediction are questionable.

The USGS prediction accuracy of volcanic eruption is variable. Many detection methods can be employed effectively only at a volcano which displays behavior favorable for their use.

Although such items as past experience, perceived negative public reaction, and perceived impact probability are known to affect how and if warnings are eventually disseminated to the public, little is known about the crucial link between this prediction and forecast agencies, and warning dissemination. Public response is the ultimate reason for having any warning system. The lack of serious attention given to it in warning system preparedness, and to research to assist in planning those systems is puzzling.

From past research efforts three important notions about how people respond to warnings have surfaced: 1. even though several persons may listen to the same warning message, there may be considerable variation in what they hear and believe; 2. people respond to warnings on the basis of how what they hear stimulates them to behave; and 3. people are stimulated differently depending on who they are, who they are with, and who and what they see.

Opportunities for Research

Two important policy questions must be considered in estimating current research opportunities for warning systems: 1. how a system should be designed to serve economically and effectively; and 2. how to ensure its adoption and maintenance.

The most decisive determinants of response in an integrated system are still conjectural. It is therefore difficult to make generalizations about how to improve warning content and dissemination procedures among the varied agencies and legal and social units in an integrated system.

Evidence suggests that many public education efforts to change warning response need improvement and that some portion of a population fails to take appropriate protective action regardless of warnings. Only with greater understanding of the likely responses of individuals and groups under disaster threat would it be possible to make precise and beneficial refinements. In situations where warning systems can function to avert large-scale loss of life and movable property, an integrated sociological and social-psychological all-hazard research project could refine present knowledge and expand upon it.

An examination of warning-response across different hazards would require that a minimum of 50 actual events be studied in order to provide an adequate sample and to ensure that the findings are generalizable. It would be more fruitful and less costly in the long run than individual hazard-specific studies. It would allow for standardization of instruments of measurement, permit a variety of factors to be controlled for in each hazard event, and make the results comparable.

The study should include events of major hazard types, in which random samples of the public exposed to warnings in each event are assessed for: exposure to the message, belief, understanding and misinterpretation, knowledge of appropriate action, and behavior. They should be examined in association with response to different kinds of threat situations, circumstances, communities, and groups of people (for example, the aged, the poor, the experienced, and the fearful).

Need also exists to determine how differences in the warning source, the message content, and the mode of communication affects psychological states in those who might respond. A series of social-psychological laboratory experiments are called for in which factors such as the number of warnings issued, specificity in warning content, and the wording of messages are related to psychological factors such as warning belief, perception of danger, and fear.

These experiments should investigate both attitudinal and behavioral effects of simulated warnings, and test the findings by field observations. The wisdom of carrying out a rigorous field experiment, as contrasted to the laboratory, is questionable, but the utility of findings could be assessed in part by comparing disaster communities in which they had been applied to those in which they were not.

Certain stipulations apply to the effectiveness of any message from a warning system: 1. if the message or signal is received at the local level without alteration, it must be received promptly and contain clear, concise information which can be easily and quickly understood by the local individual, whether official or other resident; 2. if the local recipient successfully disseminates the information to all relevant local persons, the message must be received promptly and must contain information necessary for residents to make rapid, rational decisions about appropriate actions; and 3. if the local resident interprets the message correctly, he must know appropriate action to take and be motivated to act in time. To be appropriate, action should prevent loss of life and injury, minimize property damage, and there should be a "safe area" that can be reached in time.

As demonstrated, there are many links in the effective warning chain; each link is of the same importance. Because numerous groups and government agencies divide the responsibilities among themselves, it is difficult to assure the functioning of the evaluation-dissemination sector.

A project designed to assess warning dissemination should comprise a sample of events large enough to control for varied factors such as community and hazard type. A minimum of 50 events in different communities would be necessary to assist in generalizable policy recommendations. It should address the manner in which warnings might best be disseminated, the means for overcoming economic, legal, political, and social constraints which retard warning issuance, and what changes in structure in responsible agencies would maximize good warning dissemination. It should assess all aspects of the processes preceding dissemination--detection, measurement, collation, interpretation, the decision to warn, and formation of message content--how those processes influence what is actually disseminated, and the feedback relationship from response to the dissemination process.

Warning systems cut across a variety of legal boundaries, Federal detection agencies, regional weather services, local jurisdictions and media networks. Once a particular mix of relations between these units has been found desirable for an integrated system, those measures must be adopted at local levels if the nation is to benefit. Even when adopted, the functioning systems tend to decline over time. Knowledge is seriously deficient on what affects adoption, and ensuing system maintenance at the community level.

System adoption as well as maintenance may result from a combination of factors, among them hazard repetition, community officials' awareness, and legislated requirements at the local level. Research into the adoption and maintenance of warning systems would be least costly and most efficient if integrated into one endeavor. Both components of the effort are directly concerned with preparedness. Hazard-specific research aimed at adoption or preparedness for existing systems would also be beneficial. Studies of individual hazards which are separate from each other might also be less comparable and inhibit the potential benefit which could be realized in cross-hazard comparison. The latter offers the bonus of approximating an experimental design.

No significant benefit will be attained from research on any component of warning systems unless what is currently known and what is discovered is put to use in specific communities for preparing for specific events. Research which would enable the installation and maintenance of some such systems is urgently needed. It would not center on postaudits of warning systems. There has been no comparison of dormant systems in order to determine what explains adoption and preparedness. Such a study, or even the more costly alternative of a series of studies, is central to reaping maximum benefits from warning systems, both in terms of average annual benefits or of catastrophe avoidance.

CHAPTER I

WARNING FOR A NATURAL HAZARD

A Scenario

At 9:00 AM on the morning of June 9, 1972, the National Severe Local Storm Forecast Center for the Black Hills region advised that severe thunderstorms were expected later that day in western South Dakota. The National Weather Service Office at Rapid City* then predicted severe thunderstorms in its routine release to radio and television stations that noon. At 3:40 PM a radar observer at Ellsworth Air Force Base alerted the RC Weather Service of the actual development of precipitation over the Black Hills. During the evening newscasts, from 5:30 to 6:00 PM over radio and television, however, there were no warnings of heavy thunderstorms for the area.

It was at 6:00 PM that commercial radio and television stations were requested to announce that there was high water in Boulder Canyon (an area above Rapid City) which motorists should avoid. The announcement was made by KOTA-TV, the main television station for the city, and by other stations as early as 6:15 PM. At 6:15 PM the RC Weather Service called the State Radio Dispatcher at Camp Rapid at the State Support Emergency Operating Center to obtain a report of conditions in the Piedmont to Whitewood area in the Black Hills above the town of Sturgis. The RC Weather Service was informed that twelve inches of water were on the highway west of Sturgis and that there was a report of a tornado in the area. The State Radio Dispatcher also informed the RC Weather Service of heavy rains in Hill City, located southwest of Rapid City in the Black Hills.

Radar at the South Dakota School of Mines and Technology, located in Rapid City, detected strong thunderstorms in the Hermosa area at 6:30 PM. This information was transmitted to the RC Weather Service. At the same time, the Civil Defense Director for Rapid City and Pennington County called the city police to report that three inches of rain had fallen at Pactola Dam, and that Rapid Creek was rising rapidly. It was 6:50 PM when the South Dakota School of Mines and Technology again contacted the RC Weather Service and reported that heavy rain was falling from Piedmont northwestward through the northern hills; radar at that time indicated that rain was falling at a rate of two inches per hour. This information was reinforced when the RC Weather Service received a report from Galena at 7:00 PM that four inches of rain had fallen since 5:00 PM. Ten minutes later the RC Weather Service called the River District Office in Sioux City to relay rainfall reports, inform them of a possible flash flood situation, and to request the advice and guidance of that office.

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*Hereafter referred to as RC Weather Service.

At 7:15 PM a radio station in Sturgis received a flash flood warning from the RC Weather Service and advised the RC Weather Service of a 6:00 PM report of the occurrence of flooding in Boulder Canyon. At that time the RC Weather Service issued a flash flood warning for the northern hills on a telephone hot line that connects them to radio and television stations. No mention was made at that time, however, of Rapid Creek or of any threat to Rapid City. The same information was received from the RC Weather Service by the Rapid City Police Department at 7:19 PM. The State Radio at the Camp Rapid Emergency Operations Center, however, did not receive the warning; it is this radio which serves all state agencies. In addition, the RC Weather Service did not put the warning out on the South Dakota portion of the National Warning System, which is a standard procedure for many Weather Service Offices under such circumstances.

It was at about 7:30 PM that the mayor of Rapid City was advised of the flood warning, that off-duty National Guardsmen were recalled to duty, and that the hydrologist in charge of the River Forecast Office advised the Sioux City River District Office that flash flood warnings should be expanded to the south and that affected creeks and canyons should be named. At about this time KOTA-TV began to receive reports from persons in upstream areas along Rapid Creek concerning the heavy flow of water in the creek. One such report came from the tender of Pactola Dam. KOTA-TV personnel then became concerned that there might be a flood of some unknown magnitude, and the newsroom of the station began to monitor law enforcement broadcasts. The Sioux City River District Office advised the RC Weather Service at 7:45 PM of a bulletin it had received from the River Forecast Center fifteen minutes earlier. At about the same time an unknown person in Nemo advised the RC Weather Service that Box Elder Creek was flooding, that two dams upstream had broken, and that the low-lying areas in Nemo had been evacuated. As a result, at 8:00 PM the RC Weather Service amended its earlier flood warning to include Box Elder and Rapid Creek drainages. This was the first formal message which suggested that the Rapid Creek drainage might flood. At this point KOTA-TV began to interrupt its television programming to report flood information as it was received.

At approximately 9:00 PM the commercial telephone service at the RC Weather Service became intermittent and unreliable as a result of the extreme weather. The RC Weather Service advised radio and television stations at 9:30 PM that radar indicated that heavy rains would continue to fall until about midnight. Somewhere between 9:30 and 10:00 PM both KOTA radio and television abandoned their regular programming and began broadcasting straight news. At first they told only residents of Dark and Cleghorn Canyons to get to higher ground; it still was not expected that the flood would pose any major threat to the city itself.

KOTA was the only radio station on the air at that time, although other television stations besides KOTA continued to broadcast. Among these was cable television from Denver, Colorado. KOTA advised the curious to stay in their homes and asked people not to sightsee in the area. This information was broadcast simultaneously over both KOTA radio and television. At 10:00 PM the following broadcast was made:

> Torrential rains struck large areas of the Black Hills tonight and a full emergency operation is underway at newstime tonight to determine the full extent of the flooding and to rescue persons stranded along swollen creeks.
>
> All National Guard units have been called out along with all other emergency personnel. Flash flooding hit Boulder Canyon between Deadwood and Sturgis. Little Elk Creek is causing severe flooding in the Nemo area and Rapid Creek above Rapid City has risen at least four feet with the downpour and it is still raining tonight--heavily--in the stricken areas.
>
> Authorities are urging no travel in the Hills area hard-hit by the rains. Bridges are reported washed out or badly undercut in many spots. As the water has risen tonight in Rapid City--and as the rain continued--travel in western Rapid City was being restricted. Persons living along Rapid Creek are advised to be prepared for a further rise in the creek and more flooding as the water crest moves downstream and rains continue.
>
> At newstime evacuation operations are underway at the danger points. As the flood story began unfolding this evening, there were many reports of dramatic close-calls to man and vehicles. At this hour, we have no reports of serious personal injuries. Livestock losses have been reported and some buildings are reported badly damaged in hard-hit areas.
>
> Colonel Chalberg of the National Guard says the Boy Scouts in the Nemo area are safe, but word has not been received back from rescuers headed for the Girl Scout campsites (they're ok).
>
> Colonel Chalberg says 'things are bad' west of Cleghorn Canyon and all persons on or near Rapid Creek should take all precautions against more flooding.*

It was 10:15 PM that the mayor of Rapid City was informed over a two-way radio that Highway 385 was flooded. At this point the mayor called KOTA and instructed them to urge people living along Rapid Creek to evacuate. He also called the police department to instruct them to send officers into the field to get persons living along the creek out; he also instructed the police department to convey the same directives to the Rapid City Fire Department. At 10:30 PM the mayor himself broadcast over KOTA radio and television urging the immediate evacuation of all low-lying areas of the city. Fifteen minutes later, at 10:45 PM, Canyon Lake Dam, a recreational dam on the upstream southwest margin of the city, ruptured. At 11:47 the main power transformer feeding U. S. Bureau of Reclamation Power to the city went out; Rapid City was dark and KOTA silenced until about 1:00 AM Saturday, June 10th. The flood

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*June 9, 1972, 10:00 PM news broadcast of KOTA, Rapid City, South Dakota.

crest reached downtown Rapid City at about 12:15 AM.*

The flash flood left the flood plain of Rapid City devastated. Hundreds of homes and businesses were completely destroyed; many more were damaged. Over 230 persons died because they did not receive warnings or failed to heed warnings received. Large numbers of persons were injured. Data indicate however, that hundreds of people did evacuate in time. Some left immediately after receiving their first warning, some waited for several warnings before leaving. Some individuals took movable property with them; others left in such haste that the doors to their homes remained unlocked.

The city itself responded to warnings unevenly: many emergency groups and agencies were ready for the disaster, while others were not. Few were ready to respond to the large scale of the disaster when it actually occurred.

Purpose

The scenario is factual, but speaks only of one disaster event. However, it raises several important general questions about warning systems: (1) why do some people respond adaptively and in time to disaster warnings, while others do not?; (2) why can some communities get good warnings out in time to persons in danger, when a large number of locales continue to be plagued by inadequate warnings?; and (3) what research can be done to upgrade warnings and response to warnings in order to reduce losses from hazards for which warnings are possible?

It is the purpose of this report to review and assess what knowledge exists on warning systems, to reveal areas of research opportunity, and to comment on the character of those research arenas.

The main conclusions reached in the report can be summarized as follows: (1) warning systems must be assessed from an integrated perspective which includes every stage from the first sighting or forecast of a hazard to public response; (2) the knowledge which does exist on warning systems is not being put to full use in warning system preparedness; and (3) research opportunities exist which can maximize the benefits to be gained from warning systems.

The areas in which inquiry promises useful results center around the social and psychological factors which affect public warning response; the various links in warning systems between the variety of groups and agencies which evaluate threat information and disseminate

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*The city had provisions to sound fixed sirens in such a situation; however, they were not sounded that night.

public warnings; and means to encourage the construction and maintenance of integrated warning systems in adequate programs of preparedness.

Relationship to Hazard Reports

Individual hazard reports have been prepared by the Assessment of Research on Natural Hazards project, in which warning research specific to each separate natural hazard is discussed. For example, although this report raises a warning system research question concerning the hurricane hazard, specific recommendations regarding that research are found in the hurricane hazard report.

The cross-hazard warning research issues discussed in this report are related to warning research recommendations in the hazard reports in several ways. First, warning dissemination research has been mentioned in several hazard reports. It is suggested, despite differences in hazards, that such research is conceptually *the same* across several hazards. One need not study only floods to discover the key factors which account for how flood warnings are disseminated; generalizations regarding this basic warning system process can be discovered by assessing other hazard warning systems. A more fruitful, timely, and less expensive way to approach the issue would be to conduct cross-hazard research on warning dissemination (or warning response, system adoption, or preparedness research).

Second, in certain hazard reports, the conclusion may be that to study warning response, for example, would not significantly reduce average yearly losses or social disruption. This does not exclude the use of that hazard in studying the basic components of warning systems across hazards for two reasons: (1) that hazard could still be used in research on basic warning system processes, if findings can be generalized to hazards where the application of findings *would* substantially reduce loss; and (2) the application of findings to hazards where no gain could be expected in annual *average* losses still would function to reduce the catastrophe potential of that same hazard.

Finally, research opportunities which are specific to technology for predicting and warning of individual hazards are to be found in the hazard reports in this series, although the state of the art for each hazard is discussed in this report.

Hazard Characteristics and Warning

The scenario illustrates several vital roles warning systems can play in some natural disasters: they can mobilize parts of the community and relevant emergency groups and organizations within the community for response to the disaster when it comes; they can save lives and some movable property; reduce injuries; and maintain awareness of the hazard and openness to considering other possible adjustments. Pre-event mobilization and readiness can serve to combat the actual hazard during impact--for example, the sandbagging of a river bank--as well as to prepare the community for response after impact. The pre-event mobilization of emergency groups and organizations, and the community as a whole, can upgrade immediate response after impact to reduce injuries, social disruption, and deaths by the reduction of secondary hazards (fire) and through immediate search and rescue efforts.

However, warning systems perform these functions only for hazards where current levels of knowledge and technology allow the detection of danger prior to the hazard occurrence. For example, tornado warnings exist only because the detection and forecast of danger from the imminent strike of a tornado are possible. Earthquakes are not yet predictable, so earthquake warnings are impossible.

Fifteen natural hazard agents were examined in this report:

- avalanche
- coastal erosion
- drought
- earthquake
- flood
- frost
- hail
- hurricane
- landslides
- lightning
- tornado
- tsunami
- urban snow
- volcano
- wind

These agents present a wide variation of physical characteristics, of which predictability is only one. Each characteristic has implication for warnings, as well as for what might be considered appropriate response to warnings. A review of these characteristics will reveal how the physical aspects of individual hazard agents affect warning.

1. Predictability

One of the most important factors for warning is the degree to which a hazard's strike can be predicted. Several hazards are currently unpredictable, and others, such as hurricanes and long-term floods, are predictable but with varying degrees of accuracy. Predictability not only determines if warnings can occur, but in general, "the more accurate the prediction as to the location of the threat, the more effective the response may be by the population affected" (McLuckie, 1970a, p. 11).

2. Speed of Onset and Area Affected

For hazards which strike a community quickly, the warning period is short, fewer people are likely to receive a warning, and there is little time to respond. Hazards which allow for longer periods of warning may, as a result, enable better warnings and more comprehensive protective actions to occur.

The total geographical area threatened also has implications for warning. Threats to large geographical areas create problems of warning more people and working through many more media and organizations. Threats to smaller geographical areas permit more concentrated warning efforts in which coordination may be less of a problem. Dynes (1969, p. 65) and McLuckie (1970a, p. 9-10) have both suggested that warnings of the threat of associated hazards after initial impact, such as for fire after a tornado, might be easier in disaster situations which affect small geographical areas. In such cases community coordination is left more intact and fewer persons are directly involved, which may make the dissemination of additional warnings easier.

Based upon these two characteristics, the following types of hazards can be classified (Carr, 1932): (1) fast-widespread; (2) fast-localized; (3) slow-widespread; and (4) slow-localized.

Fast-widespread disasters occur with little or no warning and affect a wide area. This type of disaster is caused by an agent like an earthquake. Fast-localized disasters, caused by such agents as tsunamis, may provide little time for warning but the scope of impact is limited.

Slow-widespread disasters are caused by agents such as hurricanes and droughts. Like earthquakes, hurricanes can impact a wide area, however, a warning can precede the disaster, which frequently gives a community the opportunity to take adaptive behavior. In the case of a hurricane this may be the evacuation of the threatened area, mobilization of emergency organizations, and preparations for assisting disaster victims such as the opening of shelters. Warnings, however, must cover large geographical areas.

Slow-localized disasters, such as those which could result from a long-term flood, allow enough time for warning and warnings can be for specific and relatively small geographical areas.

3. Recurrence

Communities which are repeatedly struck or threatened by a particular kind of natural hazard sometimes develop fairly routine responses. For example, they may become fairly expert at coping with disasters due to tornadoes and floods. Warning efforts preceding these recurrent disasters in such communities assume a more organized character than they would in communities which have had little experience with the disaster agent (Eliot, 1932; Moore, 1964).

4. Length of Forewarning

Another characteristic of natural hazards which can influence warnings is the length of possible forewarning: time available between warnings and the hazard's strike. This should not be confused with the speed of onset of a hazard agent. A disaster agent which is rapid in onset, for example a tsunami, can have a relatively long period of forewarning. This time factor is critical to the warning process because it is time which allows for the adoption of protective action before impact (Dynes, 1969, p. 63).

5. Duration of Strike

The duration of the actual strike of the hazard agent also has consequences for warning (McLuckie, 1970a, p. 9). First, the content of a warning, if prescriptive statements are made concerning appropriate response, will differ; appropriate protective action will be different because warnings of lengthy hazards can also come during impact and be adjusted for actual dangers. Second, agents of longer impact may complicate the issuance of warnings concerning secondary hazards, for example, fire or contaminated water.

6. Controllability

Hazard agents also differ in the degree to which they can be physically controlled. If a flood is perceived as controlled by some protective work, warning disseminators may be reluctant to alarm the populace of a threatened community.

7. Destructive Potential

The potential destructiveness of a hazard agent is relevant to warning in two ways: first, the type of pre-event warnings to be issued are based on an assessment by the warning disseminator of what is likely to happen; second, the damage and disruption actually produced inhibit warnings of secondary threat.

The threat the agent poses to life is a critical aspect of this characteristic of hazards. Urban snow would not evoke the dramatic warnings and response connected with a tsunami's probable strike.

Although treated separately, different combinations of these characteristics can also have consequences for warning. Table I-1 ranks the 15 natural hazards in terms of several of the aforementioned characteristics. As the table illustrates, few hazards are the same in the ways combinations of their physical characteristics affect warning. However, despite these differences, the basic processes of warning--detecting the hazard, forming a warning message, and dispersing that message to an endangered public--are the same.

It should be obvious after a review of the physical characteristics of natural hazards that the forecast of a hazard like a flash flood (which results in warnings of almost immediate disaster onset) is quite different from the forecast of a hazard like drought which might last for several years. They differ not only in terms of the physical components of the hazard, but, more importantly, they differ in terms of appropriate protective *social response* to warning.

The physical characteristics of natural hazards can be transposed into two social factors: what to do about the threat, and how much time there is to do it. Hazards which can be forecast and which pose *immediate* threats to life and property can be seen as hazards for which what might be termed "dramatic event warning systems" can exist. Such a system is able to provide warning of rapidly approaching catastrophe and thereby save lives and some movable property, as well as reduce injuries and social disruption.

TABLE I-1

SELECTED HAZARD CHARACTERISTICS IMPORTANT TO WARNING

HAZARD	HAZARD CHARACTERISTIC[1]			
	SPEED OF ONSET	SCOPE OF IMPACT	DURATION	PREDICTABILITY
Avalanche	Fast	Small	Short	No
Coastal Erosion	Slow	Large	Long	Some
Drought	Slow	Large	Long	No
Earthquake	Fast	Medium	Short	No
Flood	Fast-Moderate	Medium	Moderate	Some
Frost	Moderate	Medium	Moderate	Some
Hail	Fast	Medium	Short	Some
Hurricane	Moderate	Large	Moderate	Some
Landslide	Fast	Small	Short	No
Lightning	Fast	Small	Short	Some
Tornado	Fast	Medium	Short	Some
Tsunami	Fast	Medium	Short	Some
Urban Snow	Moderate	Medium	Moderate	Some
Volcano	Fast	Medium	Moderate	Some
Wind	Fast-Moderate	Large-Medium	Moderate-Short	Some

[1] This classification of agent characteristics is a general one. Variation may well be found between agents which are similarly ranked on any one characteristic.

CHAPTER II

AN INTEGRATED WARNING SYSTEM FOR THE DRAMATIC EVENT

Warning is currently possible for flood, tornado, tsunami, hurricane and, to a lesser degree, wind and volcano. Response to warnings of these hazards is required in the face of immediate danger to life and property.

It is the purpose of this chapter to describe the warning system for such hazards and to detail the status of current knowledge on the varied components of such a system. Any future knowledge on the predictability of other natural hazards (such as earthquakes) will make the following discussion relevant to those hazards. This discussion may also be pertinent to man-made hazards (such as bombings).

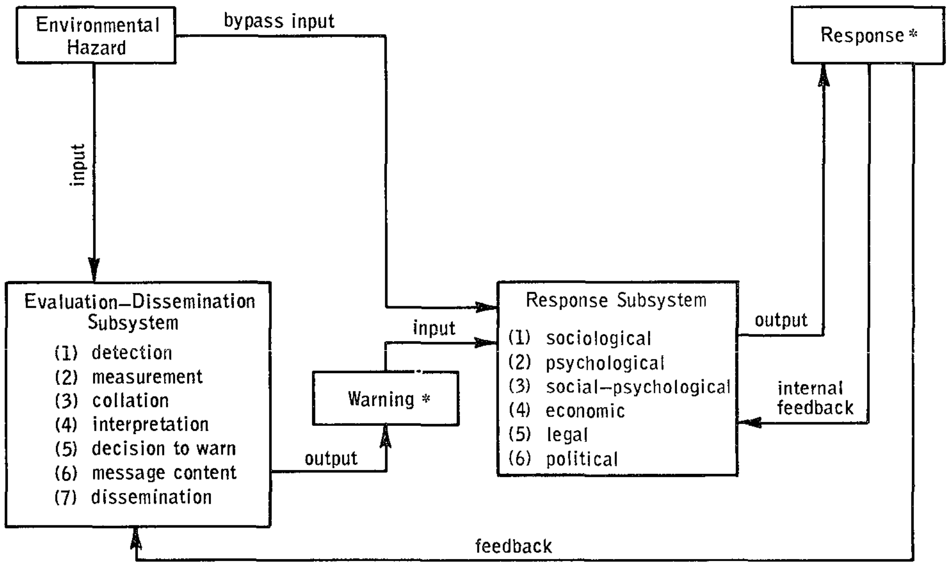
Definition of the Warning System

Warning systems are much more than the ability to forecast a hazard's strike and/or the broadcast of warning messages to an endangered public. In order to understand a public threat message, how it comes to be, and, most importantly, its consequences for persons in danger, it is necessary to view a total or *integrated warning system*. Placing hazard warnings in the context of an integrated system has the advantage of bringing to view *all* the parts of a warning system, as well as the links between them. Such a warning system is illustrated in Figure II-1. The simple analogue model proposed has been adopted from one suggested by Williams (1964, p. 83), and integrates both the technological and social components of warning systems.

An integrated warning system performs three basic functions (Moore, *et al.*, 1963, p. 15; Williams, 1964, p. 82; McLuckie, 1970a, p. 14; 1973, p. 15-16): (1) *evaluation* of the threat; (2) *dissemination* of the warnings; and (3) *response* to those warnings. Each function is performed by a variety of different groups and individuals. These functions (each of which is composed of several different but related

FIGURE II-1

SYSTEMS MODEL OF A WARNING SYSTEM



* Major dependent variables in the system.

processes) have been segregated into two warning subsystems in Figure II-2. These are the evaluation-dissemination subsystem and the response subsystem. The functions of evaluation and dissemination have been combined into one subsystem in the model in order to simplify the explanation of some of the relationships in an integrated warning system.

Evaluation, the first function of an integrated warning system, is the projection, by relevant forecast groups and organizations, of the extent of threat from a hazard to a human community. It is composed of different processes which take place between the time a hazard is detected and the time a warning message is conveyed to emergency groups in a community. The processes--detection, measurement, collation, and interpretation of available information on the threat--can be performed by persons in organizations both within and outside the community in danger.

Detection may occur in a highly specialized organization such as the National Weather Service (NWS) through the use of sophisticated technological devices. NWS personnel may first determine the presence of meteorological conditions associated with tornadoes. It is possible that the first detection of a funnel cloud may be made by an individual outside public safety agencies; however, the collation and evaluation of initial and additional information concerning the hazard are usually performed by some formalized hazard-related organization such as the National Weather Service, for which such tasks are part of its normal operations. Such organizations usually convey threat information to emergency groups within the endangered community who, in turn, disseminate warnings to the public. This link between organizations concerned with the processes of evaluation and those disseminating warnings to the public has been repeatedly shown to suffer from difficulties in many disaster events.

Dissemination of a warning message to individuals in danger is the second basic function of an integrated warning system. It may be, but more likely is not, performed by the agency involved in threat evaluation. Although an agency such as the National Weather Service may determine the threat, and give that information to community warning disseminators, the actual conveyance of the warning message to the threatened public is usually done by radio and television stations, police and sheriff departments, and, in some cases, sirens. The issuance of warning is often based on the agents' perceived needs for public response.

The dissemination of adequate warnings to the endangered public has also been shown to be a weak link in warning systems as they are now structured. In addition to the actual transmission of warnings to the public, Williams suggests that the dissemination function includes "decisions on who should be warned, about what danger, and in what way" (1964, p. 82). Also included within this function is the preparation of the content of the warning message.

This dissemination-reception process is the major link between the evaluation-dissemination system and the response subsystem of the warning system model proposed in Figure II-1. It is the purpose of the former to activate the latter. The most elaborate prediction and forecast procedures are irrelevant if the system does not warn members of an endangered public to take protective actions.

Response is the third basic function of an integrated warning system. It is the adoption of protective behavior on the part of those who receive warning: individuals, small groups, organizations, and the community itself. Such behavior is preceded by interpretations of warnings by those who respond. Both interpretations and actual behavior are the result of many sociological, social-psychological, and psychological factors discussed in a later section of this chapter.

This component of warning systems to date has received the least amount of attention in constructing and preparing for the use of hazard warnings, yet it is the sole purpose of all other warning system parts. The true effectiveness of any warning system can only be measured in terms of response.

Other dynamic links, illustrated in Figure II-1, exist between the different parts of an integrated warning system. One of these shows that response is not solely dependent on the formal warnings issued from the evaluation-dissemination subsystem, it is also affected by the hazard itself. Response may result from observations of threatening skies, a lot of rain, or the actions of neighbors. Conversely, a warning may be ignored because the sky is clear and the sun shining. This link between the hazard and the response subsystem is labeled as "bypass input" in the model proposed in Figure II-1.

Warnings or advice received from friends or relatives can also affect an individual's decision to evacuate. The warnings an individual receives are not only those officially issued from the evaluation-dissemination subsystem. This link between different persons in the response subsystem can be called "internal feedback." Illustrated in Figure II-1, it accelerates the rate at which people are exposed to warnings and either do or do not respond.

Another feedback link exists between the two subsystems of an integrated warning system. The actual response of people within the response subsystem should, but often does not, serve as information to those persons issuing formal warnings. This feedback, according to Williams, should consist of "information about the. . .actions of recipients to the issuers of warning messages," and results in "new warnings, if possible and desirable corrected in terms of responses to the first warning messages" (1964, p. 83). Unfortunately, such monitoring of response to measure the effectiveness of formal warnings is rarely performed or provided for in warning systems.

The effectiveness of a warning system can be measured only in terms of the degree to which protective response (which differs in content depending on the hazard and degree of threat posed) is elicited in the threatened public. However, several prominent factors serve to inhibit the development, adoption and maintenance of integrated warning systems.

Constraints to the Warning System

Two types of constraints exist for integrated warning systems: those which inhibit the development and adoption of such systems at local levels, and those which reduce the effectiveness of warning systems when in operation.

Perhaps the strongest constraint to the development of warning systems is that they deal with very infrequent events. As a consequence, communities give a low priority to the establishment or maintenance of any warning system. This constraint also serves to weaken the links between whatever components of a warning system do exist, thereby reducing the effectiveness of the warning system when put into operation. Poor communication exists between those who evaluate threat and those who carry that information to the public. Public warning disseminators usually proceed without sufficient knowledge or training in what information should be contained in public warnings, or the best means for delivery. The result is often an inadequately warned public and needless deaths and injuries.

Other constraints reduce the effectiveness of warning systems: (1) technical problems in accurate assessment and prediction of the event, and in getting that information to public warning disseminators;

(2) inadequate community preparedness or organization; and (3) community disseminators not knowing how and what information should be publically dispersed in light of the varied sociological, social-psychological, and psychological factors which affect an individual's response to hazard warnings. These constraints focus on the links between the varied components of the integrated warning system modeled in Figure II-1.

Status of Knowledge

Two types of knowledge are relevant to any warning system: technological knowledge for hazard forecasting, and social scientific knowledge for the structure and operation of the warning system. An assessment of the status of technical knowledge for the prediction and forecast of each natural hazard of concern is presented in Chapter III. It is the purpose of this section of this chapter to review social scientific knowledge concerning the evaluation-dissemination and response subsystems of the warning system model proposed in Figure II-1. Although this discussion presents the central known issues for response, a more detailed discussion can be found in Mileti, Drabek and Haas (1975).

1. The Evaluation-Dissemination Subsystem

Researchers have tried to determine what factors explain differences in warnings issued from the evaluation-dissemination subsystem of warning systems (see Anderson, 1969a; Dynes, 1970; Fritz and Williams, 1957; Fritz, 1961; and Kennedy, 1970). Although knowledge is still rudimentary, three basic elements have emerged as central in explaining how warnings are issued: (1) the experience of community and agency officials in warning roles; (2) the pre-event structure and organization of warning-related community agencies; and (3) the nature of actual disaster-related communication between warning-related agencies.

The past experience of officials in charge of issuing warnings may provide reference points that give a false sense of security and lessen the sense of urgency (increase delay) and the adequacy of the warning. The effectiveness of warning varies directly with the range of past error in the predictability of the disaster agent. However, prior disaster experience may also provide learning experience that has a positive effect on warning. In the extreme case, a substantial amount of disaster experience can result in the development of a disaster subculture, that is, the group culture would include special routine ways of dealing with crisis. This results in some high level of community preparedness (Dynes, 1970), and increases the probability of rapid and adequate warning.

Officials are likely to be reluctant to issue a specific warning until they are reasonably certain that the danger will materialize. The possible negative public reactions include the consequences of issuing a false alarm and the myth of anticipated panic. Visible changes in the physical environment, for example, a river rising over its banks, can increase the likelihood of an official issuing a warning (Anderson, 1969a).

The pre-disaster social structure of community organizatons also helps to explain disaster warnings. The capacity of any community organization for communication can determine the involvement of that organization in the warning process. For example, police departments usually become involved as a key link in the dissemination of warnings because of their capability for communication (Kennedy, 1970).

Communication between warning-related community organizations is affected by routine daily patterns of interaction between those organizations. Warning-related agencies which do not interact during normal times may experience more difficulty in transmitting warning-related information to each other in times of impending disaster. Warning-related interorganizational communication is also inversely related to an organization's perceived self-relevance for disaster; a police department's perception of itself as a key agency in disaster may result in a reluctance to keep other community agencies informed. Such pre-disaster event organizational considerations affect the speed, manner, and form of interaction between warning-related organizations, and, consequently, the nature of warnings issued to a community (Kennedy, 1970).

In any event, however, the actual nature of interorganizational communication is related to the probability of issuing warning (Anderson, 1969a; McLuckie, 1970a). It can be said that (1) the ambiguity in interorganizational emergency bulletins is directly related to delay in issuing warning; (2) the clarity and completeness of the information sent between warning-related organizations is directly related to the probability of issuing warning; and (3) the speed of interorganizational communication is directly related to the probability of issuing warning.

Although these factors have been found as central in explaining differences in warnings issued from the evaluation-dissemination sector of warning systems, the picture is far from complete. Not enough is known to allow us to make, with great confidence, policy recommendations about how to better organize the various organizations and groups which perform these basic warning system functions. One of the questions posed at the outset of this report still remains largely unanswered: why can some communities get good warnings out in time to persons in danger, when a large number of locales continue to be plagued by inadequate warnings?

2. The Response Subsystem*

The status of knowledge concerning response to pre-disaster warnings can best be summarized by segregating the discussion into three categories: individuals and small groups; complex organizations; and communities and societies. Such a classification was developed because it enables the presentation to be made with minimum repetition. Those factors which help explain warning response for individuals have been found to be conceptually the same as those which explain the response of small groups such as the family.

a. Individuals and Small Groups

The response of individuals and families to disaster warnings has been studied from a variety of perspectives both within and between the fields of sociology, social-psychology, and psychology (see Killian, 1952; Instituut Voor Sociaal Onderzoek Van Het Nederlandse Volk Amsterdam, 1955; Clifford, 1956; Diggory, 1956; Form and Loomis, 1956; Fritz, 1957; Danzig, *et al.*, 1958; Mack and Baker, 1961; Bates, *et al.*, 1963; Moore, *et al.*, 1963; Anderson, 1969a; Drabek, 1969; Sims and Bauman, 1972; Haas and Trainer, 1973; Mileti, 1973).

From all past research efforts three important notions about how people respond to warnings have emerged: (1) even though people may be *listening* to the same warning message, everybody *hears* and *believes* different things; (2) people respond to warnings on the basis of how what they *hear* stimulates them to behave; and (3) people are stimulated *differently* depending on who they are, who they are with, and who and

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*A popular misconception concerning response to threat has been to expect *public* panic to be a typical response; this is not the case (Quarantelli, 1954; Fritz and Marks, 1954). Fritz (1957) has outlined the rare circumstances when panic can occur, and Quarantelli (1964) has offered a profile of the panic participant.

what they see.

Although the specifics are too detailed and numerous to be reviewed here, Figure II-2 is presented to give the reader a summarized overview of the relationships between those factors which are involved in explaining response to warnings. Although the relationships modeled in Figure II-2 are based on a variety of research efforts, they are supported with different degrees of evidence and should be interpreted with caution.

Figure II-2 illustrates the complexity of relations between factors which help explain warning response. It also illustrates the central roles of warning confirmation (obtaining additional or supportive information beyond that contained in a warning) and warning belief (believing that the threat alluded to in a warning is real) in explaining response to warnings.

As Figure II-2 and Table II-1 illustrate, people respond to hazard warnings differently on the basis of their pre-event composition, which is unchangeable (their age, experience, socioeconomic status, and locus of control), and of those portions of their composition which an actual warning event influences and changes (perception of danger, how many warnings they receive, and the content of the warnings they receive).

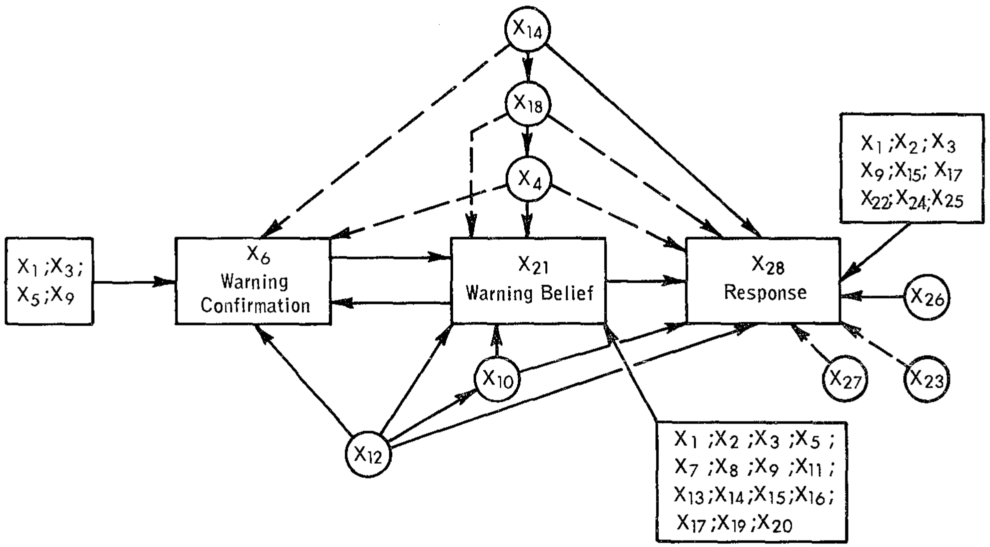
A recent study (Mileti, 1974) suggests that fear is a critical factor in explaining response to hazard warnings. The study suggests that warnings should be constructed to maximize peoples' definitions of danger, but not to elicit high levels of fear. The lack of the former or presence of the latter are likely to produce inadequate warning response.

The compilation of factors and relationships in Figure II-2 is an attempt to integrate the findings of dozens of independent and largely unrelated research efforts on response to warnings. Because of the low degree of comparability between each of these efforts, little is known about: (1) whether these factors really make a difference for *all* types of natural hazards; (2) if some factors are more important than others; and (3) which factors are most important.

Furthermore, several areas of concern which could be policy-relevant and central to warning system effectiveness have not been studied sufficiently in reference to natural hazards: (1) the efficacy of sirens in upgrading response; and (2) formulation of the content of the warning message to increase belief in danger but not cause fear.

FIGURE II–2

MODEL OF RESPONSE TO PRE–IMPACT WARNINGS
SUGGESTED BY THE RESEARCH REVIEW



Where:— — = indirect relationship; ——— = direct relationship or no direction specified; X_1 = warning source X_2 = warning content; X_3 = communication mode; X_4 = number of warnings received; X_5 = perceived warning certainty; X_6 = warning confirmation; X_7 = interpretation of environmental cues; X_8 = observed action of others; X_9 = primary group context; X_{10}=situational hazard perception; X_{11} = previous hazard perception; X_{12}=personal experience; X_{13}=experience of others; X_{14}=geographical proximity to target area; X_{15}=socioeconomic status; X_{16}=organizational membership; X_{17}=sex; X_{18}=age; X_{19}=urban/rural residence; X_{20}=race; X_{21}=warning belief; X_{22}=normative context; X_{23}=perceived time to impact; X_{24}=role conflict; X_{25}=ethnicity;X_{26}=psychological locus of control; X_{27}=fear; and X_{28}=response.

TABLE II-1

SELECTED EXAMPLES OF THE RELATIONSHIPS IN FIGURE II-2

(1) Any warning message broadcast, especially the early ones, will be accepted at face value only by a minority of the recipients. Most will engage in confirmation efforts for a time.

(2) The more warning messages received by an individual, the fewer the attempts at warning confirmation.

(3) The closer a person is to the target area of a warning, the higher the incidence of face-to-face communication and the larger the number of sources used in confirmation attempts.

(4) Warnings from official sources (police, state patrol, fire department) are more likely believed.

(5) Message content per se influences belief. The more accurate and consistent the content across several messages, the greater the belief.

(6) The more personal the manner in which a message is delivered, the more it will be believed.

(7) Belief in eventual impact increases as the number of warnings received increases.

(8) The recipient's sense of the sender's certainty about the message is important to belief.

(9) Message believability is related to what happens in the confirmation process. The response of official sources to questions which call for validation, corroboration, or refutation helps determine believability.

(10) A person is more likely to believe a warning of impending danger to the extent that perceived changes in his physical environment support the threat message.

(11) Persons who see others behaving as if they believe a warning to be valid are themselves more likely to believe the warning.

(12) Past experience may render current warnings less credible if disaster is not part of experience, or more credible if disaster is part of experience.

(13) The closer a person is to the target area of warning, the more rumors he will hear and the less accurate will be his understanding of the character of the forecast events.

(continued)

Table II-1, continued

(14) Persons do not readily evacuate on the basis of the first warning received, and the number of warnings received thereafter is directly related to evacuation.

(15) As the warning message increases in its accuracy, and/or information about survival choices, and/or consistency with other warnings, and/or clarity about the nature of the threat, the probability of adaptive response increases.

(16) Whether or not a person takes action depends on his belief in the warning message. But even if he believes, he may fail to take *adaptive* action due to his misinterpretation of the meaning of the message content.

(17) Evacuation tends to be a family phenomenon. The best way to accomplish evacuation appears to be repeated authoritative messages over broadcast media which stimulate discussion within the family and lead to evacuation (if it is going to happen at all).

(18) Persons receiving face-to-face warnings in a family setting from authorities are more likely to evacuate.

(19) Persons with recent disaster experience are more likely to take protective actions.

(20) Perceived amount of time to disaster impact is also important.

(21) Belief that impact could occur at the location from which a person may be about to evacuate is critical.

(22) Older persons are less likely than the young to receive warnings regardless of warning source, and less likely to take protective actions.

(23) Regardless of the content of a warning message, people tend to define some potential impact in terms of prior experience with *that specific* disaster agent.

(Adapted from Haas, 1973)

b. Complex Organizations

Few studies have been made to assess the response of formal organizations to pre-impact disaster warnings. Most research efforts have been directed toward the study of how organizations mobilize to combat the disaster after impact has occurred. Based upon several studies (see McLuckie, 1970; Adams, 1971; Thompson and Hawkes, 1962; and Barton, 1962), the following generalizations present themselves as applicable to the pre-impact warning period.

It can be stated that the bureaucratic structure of an organization affects organizational response to pre-impact warnings. Strongly established patterns of centralized decision-making may delay action prior to impact. In addition, the greater the continuity between disaster roles and the normal responsibilities of an organization, the less problematic disaster mobilization is likely to be. It can also be stated that as the role conflict of organizational members increases, the ability of the organization to mobilize decreases. Organizational members whose families are not threatened are joined by other organizational members only after their family obligations have been satisfied. In general, other roles compete with organizational mobilization and may leave the formal organizations short of, or entirely without personnel.

c. Communities and Societies

As was the case with the mobilization of complex organizations, the mobilization of communities in disaster has been typically studied as a post-impact phenomenon. The following generalizations concerning the pre-impact response of units larger than complex organizations can be advanced on the basis of several significant studies (see Eliot, 1932; Moore, 1956; Barton, 1970; Dynes, 1970; Anderson, 1969a; McLuckie, 1970; Clifford, 1956; Sjoberg, 1962; and Instituut Voor Sociaal Onderzoek Van Het Nederlandse Volk Amsterdam, 1955).

In societies where catastrophe is thought to be caused primarily by spiritual forces, man does little to alter the course of events apart from recourse to religious and/or magical practices. Such basic beliefs in a social system or society are relevant in explaining the pre-disaster mobilization of that society for disaster

Rural populations have been found to be more reluctant to evacuate than urban populations. From this we may imply that the degree of urbanization in a social system is related to the mobilization of that social system.

In societies where the family institution is dominant, there will be more reluctance to evacuate. We may state that the pervasiveness of the family institution in a social system is related to the mobilization of that social system in the pre-impact period. In addition, the basic social structure of a community has been found to be related to the pre-impact mobilization of that community. Strongly established patterns of centralized decision-making may delay emergency preventive actions prior to impact in cases where individual agency members wait for decision approval by superiors; yet even in cases where no agency or set of bureaucratic instructions exist, problems for system mobilization arise.

Past disaster experience at the community level may provide learning experience that has a positive effect on the response of that community to disaster. The extreme outcome of positive past experience is the development of a disaster subculture.

d. Recommendations

On the basis of the knowledge which does exist about response to warnings, several policy recommendations can be made. This information should, until we have more in-depth knowledge, be translated into practical action and put to use by those concerned with warning preparedness.

Warning systems are comprised of progressive chains of communication among a variety of agencies and organizations which ultimately lead to the public. The effectiveness of these systems decreases over time, in part due to the limited interaction among the components of the system between threats from hazards. If inter-agency and interorganizational communications in warning systems increased in specificity, consistency, clarity, and speed, the result would be the dissemination of better public warnings. Local preparedness must incorporate the establishment of links with all warning-related organizations, and seek to maintain channels of communication during daily operations. This might be accomplished, for example, by the integration of hazard warning systems with all-purpose emergency systems, and the establishment of direct lines of interaction (such as telephone hotlines) with forecasting agencies and dissemination agencies for emergencies. Either by altering existing routine interaction patterns among these agencies to increase daily interaction, or by establishing low-vulnerability communication links for emergencies, the integration of present systems could be upgraded.

Agents who have the prime responsibility of dispersing public warnings, whether they turn out to be a town mayor, police chief, or radio and television broadcasters, disseminate warnings in terms of past experience, perceived negative consequences, and the specificity, consistency, and clarity of information which they themselves receive. With these issues in mind, preparedness can upgrade the effectiveness of a system by formalizing guidelines for when, how, and what messages will be released to the public. Determined by "triggers" (points at which previously established plans dictate that public warnings be dispersed) within the content of forecasting agency advisements, preparedness could detail warning procedures, mechanisms of information dispersion, and previously established public messages of specific content.

The *content* of these messages might well be prepared in terms of what we know is likely to encourage adaptive response in a populace. In addition, the process of an individual confirming a threat message is central to any ultimate protective actions he might take. Warnings should be consistent in *content* to help aid this process.

The content of warning could be upgraded by adequate local risk delineation. For example, for floods, tsunamis, and volcanoes, detailed delineation of areas which might be affected would enable warning and evacuation advisements to be more specific in directions. For hurricanes, severe storms, and other agents in which micro site-specific vulnerability cannot be established beforehand, the pre-planning of actual evacuation routes would allow the dispersion of specific warning messages. Tornado warning preparedness, since impact usually follows very short periods of forewarning, would preferably include pre-formulated message statements concerning appropriate on-the-spot protective action.

Assessments of local risk could define danger points and specify what would be appropriate response; both items should be contained in any warnings eventually issued. In that the function of detection and warning is to effect response, warning preparedness must be based on who should take responsive action. Local risk determinations would provide this information.

Preparedness should also provide for the dispersal of warnings by means other than the mass media since (1) the aged are less likely to take adaptive behavior in response to warnings; (2) the more personal the manner in which a warning is delivered, the more it will be believed and acted upon; and (3) warnings from official sources like the police are more likely believed and acted upon. Considerations like these can be operationalized into preparedness policy. For example, towns with a high geographical concentration of older persons living in a flood plain should provide in their preparedness plans means whereby the police or fire department would carry street or door-to-door warnings to that area. This would increase the chance of the old taking action.

A tentative list of policy recommendations for radio and television stations should include the following directives.

DO:

(1) Develop and maintain "fail safe" direct communications with the local National Weather Service office.

(2) Establish emergency electric power generation capability and be certain that it is checked and maintained regularly.

(3) Plan so that your station can meet its broadcast warning responsibilities even under the maximum credible "worst" circumstances (equipment malfunction, personnel absences).

(4) Make sure all announcers know exactly how to handle *every type* of warning message.

(5) Conduct several "warm-up exercises" at the beginning of each season for seasonal hazards.

(6) For floods, be prepared to give specific information on which blocks or areas are forecast to be inundated.

(7) Make all warning messages as specific as possible and repeat, repeat, repeat!

(8) Have warning messages be as personal as possible--personal in content and with well-known and highly respected persons giving the information and advice.

DON'T

(1) Give out any information unless you are quite confident of its accuracy.

(2) Broadcast an occasional warning message interspersed in regular programming *if* you want listeners to take prompt, protective action.

(3) Give out *general* information if there is a possibility of having more *specific* information to broadcast with adequate lead time. (Early, general information tends to undermine the believability of later specific information.)

(4) Assume that the listener has heard any of your earlier watch or warning messages.

(5) Assume that your listeners know what specific protective action to take.

(6) Forget that some of your listeners are strangers visiting or traveling through the area for the first time.

(7) Let months and years of freedom from disaster lull you into complacency. Lives depend on your personnel and facilities.

(8) Underplay or over-emphasize the danger. The best public response comes when *specific* information about *personal* danger is presented without going to either extreme.

(9) Refer to just any prior disaster event for background material to broadcast while a warning is in force. Have material prepared for a range of past disaster experiences and select the material that is most appropriate for the "up-coming event."

Estimates of Cost

Warning systems cut across a variety of political levels and normally consist of parts from each. Estimation of the cost of a warning system for any one hazard, therefore, must consider total cost as a combination of the cost born by each constituent part of the system. The fact that agency costs for one hazard are often (especially in the case of weather-related hazards) inseparable from groups of hazards complicates cost estimates further.

In Table II-2 we attempt to estimate, where possible, the cost of warning systems by all groups and agencies involved in terms of the three basic functions of warning systems: evaluation, dissemination and response. From those parts of warning systems for which we were able to make reasonable estimates, it can be seen that the national cost of this adjustment is well in excess of approximately $140 million annually. This estimate is itself incomplete. It says nothing of the costs involved to those agencies and groups listed in the table for which cost estimates were unavailable.

TABLE II–2
REVIEW OF WARNING-RELATED EXPENDITURES

KEY
░ Evaluation
▨ Dissemination
▩ Response

	GOVERNMENTAL AGENCIES AND OTHERS	HAZARDS															
		AVALANCHE	COASTAL EROSION	DROUGHT	EARTHQUAKE	FLOOD	FROST	HAIL	HURRICANE	LANDSLIDES	LIGHTNING	TORNADO	TSUNAMI	URBAN SNOW	VOLCANO	WIND	Yearly Cost of Operation (Million $)
FEDERAL	NOAA																
	National Weather Service	░	░	░		░	░	░	░		░	░	░	░		░	
	National Meteorological Center											░		░			
	National Severe Storms Forecast Center										░	░					
	Agricultural Weather Service						░					▨					
	Radar Report + Warning Coordination Circuit								░		░	░					
	River District Offices & Forecast Centers					░											░ 68.1
	GOES – Satellite System								░			░	░				▨ 14.2
	Environmental Data Drought Index			░													▩ 0.0
	National Hurricane Center								░								
	Hurricane Warning Offices								▨								
	Weather Service Forecast Offices			░		░	░					░		░		░	
	NOAA Weather Wire Service		▨			▨		▨	▨			▨				▨	
	Joint Effort w/Univ. of Hawaii												░				
	Flash Flood Warning + Alarm System					░											
	U.S. Department of Interior					░											░ 6.3
	U.S. Geological Survey			░	░	░				░			░		░		▨ 0.1
	Hawaii Volcano Observatory														░		▩ 0.0
	National Tsunami Warning Center												▨				
	U.S. Department of Defense																░ 21.6
	Army Corps of Engineers					░▨▩							░				▨ 8.4
	Defense Civil Preparedness Agency																▩ 19.6
	Nat'l Warning Centers & State Warning Points																

(Continued on next page)

TABLE II–2
(Continued)

KEY
▒ Evaluation
▨ Dissemination
☒ Response

	GOVERNMENTAL AGENCIES AND OTHERS	AVALANCHE	COASTAL EROSION	DROUGHT	EARTHQUAKE	FLOOD	FROST	HAIL	HURRICANE	LANDSLIDES	LIGHTNING	TORNADO	TSUNAMI	URBAN SNOW	VOLCANO	WIND	Yearly Cost of Operation (Million $)
FEDERAL	U.S. Department of Agriculture	▒				▒											
	U.S. Forest Service	▒								▒	▒						▒ 0.7
	Fire Control Offices										▒						▨ 0.0
	Soil Conservation Service					▒											☒ 0.0
	NASA	▒							▒	▒					▒		?
	Department of Transportation																?
	Federal Highways Administration	▒								▒							
STATE	Federal Disaster Assistance Administration																
	State of Calif. Div. of Mines & Geology												▒				
	Alaska Tsunami Regional Warning System												▒				?
	State Highway Departments	▒															
	State Police		▒														
	State Geological Div. + other State Agencies									▒							
LOCAL	Local Govt. Employers, Police etc.		▨			▨			▨	▨		▨	▨	▨☒	▨		
	Local T.V. + Radio		▨	▨		▨	▨		▨	▨		▨	▨	▨	▨	▨	?
	Local Geological Div. & other State Divisions									▒							
INDIVIDUAL	Private Weather Forecast			▒▨			▒▨							▒▨			
	Private Sector	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	?

(Derived from National Oceanic and Atmospheric Administration, 1973)

CHAPTER III

PREDICTION AND FORECAST

Attention will now be directed toward an assessment of the technology component of warning systems for individual hazards. Variation exists to a sufficient extent in the technology and skills for forecasting threat across hazards to warrant separate discussions by hazard. However, sufficient similarities do exist by hazard categories to allow integrated cross-hazard discussions of weather monitoring and communication systems. These two cross-hazard issues are presented at the end of the chapter.

Flood

The National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA) is responsible for preparing forecasts and issuing warnings for floods throughout the country, except in the Tennessee River Basin where responsibility is shared with the TVA. River stage forecasts are routinely issued for over 1700 points in the major river basins of the nation.

Floods are classified by the NWS into two types: those that develop and crest in six hours or more; and those that crest more quickly. The former will be referred to as "floods" and the latter as "flash floods."

The River and Flood Forecasting and Warning System costs more than $6 million annually. Twelve River Forecast Centers cover 97% of the country, including Alaska. At a second level are 82 River District Offices within the major river basins. Plans to extend a full forecasting service to other areas are being implemented. The River Forecast Centers have personnel sufficient only to operate a 40-hour week, plus limited coverage during flood periods; routine extra coverage would permit greater use of computer capacity, in combination with automated data networks, and thus provide forecasts several hours earlier (U. S. Department of Commerce, 1971). The overall forecasting proficiency of the system is unknown.

Based on flood forecasts transmitted to the River District Offices, forecasts and warnings are transmitted over the NOAA National Weather Wire Service and the NOAA VHF/FM Radio Transmission Service to organizations with receiving equipment. Other organizations are notified by telephone or telegraph. The system has four serious shortcomings: (1) the National Weather Wire Service is not available in 12 states; (2) many smaller communities and broadcasting stations apparently do not pay the $100 per month for the special service; (3) dissemination of warnings via telephone and telegraph is time-consuming and slow; and (4) none of the warnings reach the public directly--the press, radio, and TV must relay and interpret. The public must interpret the warnings, regardless of source. An individual who hears a radio warning, followed by a return to normal broadcasting, may conclude that the warning does not depict a serious situation. Public broadcasts seldom give explicit instructions on appropriate action to be taken.

The flood forecasting system is unsuitable for flash floods in smaller drainage areas. Approximately 2,500 communities of small size are estimated by NWS to be prone to flash floods (U. S. Department of Commerce, 1969), exceeding the number of communities of larger size subject to flash floods almost sixfold. NWS employs three basic approaches to prediction and warning of flash floods. The first is the Community Flash Flood Warning System by which a local official collects precipitation and streamflow reports and prepares on his own initiative a local forecast using procedures furnished by NWS and equipment at local cost. He alerts the community through a prearranged system. The cost of such a system varies considerably owing to the number and types of gauges used. LaFollette, Tennessee, installed a system in 1964 for $9,000, with annual operating costs of $3,000. Currently, 140 such systems are operative, but little is known on why other communities have not followed suit.

The second approach is the Automatic Flash Flood Alarm which activates a warning in the community when flood stages reach pre-set danger points. Only ten of these systems are currently installed, including Wheeling, West Virginia, and Green Brook, New Jersey. The system has three elements: a robot water-level sensor on an upstream reach; an intermediate station several miles downstream which provides electric power to the sensor; and an alarm station from which warnings can be disseminated, e.g., a police station ("Flash Flood Warning Systems," 1972).

The third approach is the conventional Weather Warning which depends on the expertise of the local weather forecaster, who issues a generalized warning of possible flood conditions. These techniques are changing rapidly as means of radar detection and computerized data analysis are improved.

Hurricane

There has been a significant improvement in hurricane forecasting from the 1950's, when various individuals and small groups started developing objective techniques, to the current 24-hour displacement error of approximately 100 miles (160 km).

There are two approaches to the forecasting of hurricane motion, the dynamic and the statistical. With the dynamic approach numerical models are used to predict the field of motion; the statistical approach bases prediction on a large sample of data from past storms. Both methods are presently being used, depending on which is expected to provide the most reliable forecast under the given atmospheric conditions.

Over the four-year period, 1956-1959, the mean error in predicting the distance to be covered by a hurricane in 24 hours (regardless of distance from the coastline) was 182 miles (293 km) (OEP, 1972, Volume 1). This error was reduced to 122 miles (195 km) over the period 1968-1971, which represents a 30% reduction over the last ten years, and is the result of knowledge gained from research flights into hurricanes, the availability of high-speed data processing, and, most recently, cloud motion analysis from satellite pictures. The displacement error becomes smaller as the storm approaches the coast and its motion is monitored more closely by land-based radar. The average landfall error for a 24-hour prediction is of the order of 115 miles (185 km) (Simpson and Lawrence, 1971).

The present forecasting error combines the error in determining the position of the hurricane center, and the error in forecasting the displacement. Reduction in the present positioning error (20-30 miles or 30-50 km) is well within the state of the art, and will come with improved aircraft reconnaissance systems, and with transmission and processing facilities for data acquired by these aircraft.

Reduction in the displacement error is more difficult. Interactions between meso-convective scales of motion in a hurricane vortex and the synoptic scale of motion in the environment are not yet fully understood. A more precise and systematic acquisition and processing of data from the vortex of reconnaissance aircraft and meteorological satellite is needed.

It is generally believed that although much still remains to be learned about hurricanes, a plateau for the moment in forecasting has been reached (Dunn, 1965; Sugg, 1967; Simpson and Lawrence, 1971). In the next ten years reduction in the forecasting error will probably come from astute application of methods presently in use.

The storm surge forecast, until recently, was done in a very subjective fashion. A computer model developed by Jelesnianski (1972) is now being used, which provides alternate profiles of storm surge along the open coast (excluding estuaries, irregular coastlines) in the event of landfall and other errors. The storm surge is now the most accurately predicted aspect of the hurricane (for the open coast), but this achievement is much reduced by the less accurate predictions of landfall and wind speed changes (Simpson, 1973).

An intricate, multi-tiered warning system exists, headed by the National Hurricane Center (NHC) in Miami, and five Atlantic and Gulf centers designated as Hurricane Warning Offices (HWO)--Miami, New Orleans, Washington, Boston, and San Juan, Puerto Rico--which are linked by normal NWS communications, a special Hurricane Teletypewriter Circuit, and a Hurricane Hotline Telephone. The message usually reaches the local level through the NWS office (the National Weather Wire Service [NWWS] and the Radar Warning Coordination [RAWARC]), Civil Defense (NAWAS communication net), Federal Aviation Administration (FAA), or armed forces communication system. It is then dispersed to the public by radio and television (OEP, 1972, Volume 1).

Releases from the NHC and HWO's are of two types. The hurricane *watch*, issued about 30-36 hours before landfall, alerts coastal residents and authorities to the threat. The hurricane *warning*, issued about 12-18 hours before landfall, indicates that immediate action, including evacuation from exposed coasts, is needed. In an attempt to give disaster preparedness officials a better idea of the potential impact to be expected, a hurricane intensity scale of 1-10 was used for the first time in 1973.

Tornado

The prediction or forecasting of tornadoes is difficult because of the suddenness of the onset of the hazard, the relatively short duration of the event, the extreme variability of the typical tornado striking any particular area, the level of description or knowledge of the hazard, and the extent of the weather observing system. Kessler (1970, p. 927) describes prediction:

> Forecasts of tornadoes are closely linked to forecasts of severe thunderstorms, and like other weather forecasts, these must start from a description of the present state of the atmosphere. They are less specific than we would like, partly because of a lack of understanding, but partly because our observations are too sparse to describe atmospheric variability on the scale productive of the tornado or thunderstorm phenomena. Thus, the extent of a severe thunderstorm may be 10 to 25 mi, and the lifetime of a storm system can be considered about 6 hr. On the other hand, the distance between primary surface weather stations is about 100 mi, and between upper air stations over 200 mi. Observations are made hourly at the surface stations (more often under special conditions) but usually at only 12-hr intervals at the upper air stations. Therefore, even if our knowledge were otherwise adequate to the task, the weather observing system we now have would limit us to indicating the probability of thunderstorms and accompanying tornadoes in regions much larger than the storms.

Tornado forecasting parameters are warmth and moisture levels in a layer about 5,000 feet deep near the earth's surface, with a cool dry region at intermediate levels, strong winds in the upper atmosphere, and a trend toward intensification of related conditions. Prediction is based on current meteorological readings and years of accumulated observations, analyzed by statistical and dynamic methods, and finally controlled in practice by experienced forecasters (Kessler, 1970, p. 927).

The National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA) has the responsibility for tornado prediction and forecasting. At the broadest level, information pertaining to forecasts for a 72-hour period encompassing the United States is generated and distributed by the National Meteorological Center in Suitland, Maryland. These general forecasts are transmitted to the National Severe Storms Forecast Center (NSSFC) in Kansas City, Missouri. The NSSFC has the responsibility for monitoring areas that may have severe local storms, and issuing forecasts for areas (about 25,000 mi^2) which are likely to have the most severe weather. These are known as tornado watches and they represent forecasts of severe storms and tornadoes issued one to seven hours in advance. Tornado watches are intended to alert persons to the possibility of tornadoes within the area for which the watch is issued. After the NSSFC has issued a severe weather watch, local offices of the National Weather Service have the resonsibility for tracking specific storms, and issuing public warnings. These tornado warnings indicate that a tornado has been sighted, and that persons within the local area should take protective cover immediately.

The weather service offices rely on information from several sources: (1) radar, some of which are outdated World War II radar units; (2) weather satellites; (3) electronic tornado detectors or sensors; and (4) for the actual sighting of tornadoes and funnel clouds, volunteer and professional spotters. In 1969 Project Skywarn was inaugurated to augment the detection capabilities of local weather service offices, and consists of thousands of volunteer spotters and organizations trained in recognizing the characteristics of severe thunderstorms and tornadoes. The visual sighting of tornadoes is important for the warning sequence because of the extreme variability in designating a tornado striking point.

Severe storms and tornadoes are under surveillance as they develop by National Weather Service personnel, by employees of local governments (particularly police), and by Skywarn volunteers. Project Skywarn data summaries are presented Monday through Friday on NBC's Today show.

When the Weather Service becomes aware of the existence of a tornado, a warning to communities in the extrapolated path of the storm is immediately issued by teletype, and directly by radio and television. One communications system used is National Warning System, or NAWAS. Originally designed as a defense communications system, it is now used for any emergency. This system may have some drawbacks as an effective communication system for the tornado hazard because it is a telephone-operated hotline, connecting only Civil Defense Warning Points within each warning area.

Other communication systems include RAWARC (Warning Coordination), an internal teletypewriter system for the National Weather Service and NOAA Weather Wire Service (NWWS) consisting of local loops serving metropolitan areas, statewide intrastate circuits, and overlay circuits. The system includes usually only the larger cities. The system is dependent on information fed into it, is more likely to obtain data for long track tornadoes than for the more localized, short track tornadoes. The system also does not include all of the news media, and television and radio are of particular importance in tornado warning as in any warning system. The communication system effectiveness is ultimately dependent on whether it is received by persons authorized to sound sirens and/or notify the mass media.

Although the National Weather Service is charged with the responsibility of warning the public of hazardous weather conditions, at this time the NWS dissemination of weather information is carried out mainly via the commercial broadcast system, AM and FM radio as well as TV. It is their option to transmit the warnings, and is nearly always done; however, seldom do any of these public broadcasts give explicit instructions on appropriate action to be taken by the public.

Wind

Wind in general is extremely variable in time and space. In addition, the disturbances responsible for the damaging winds are relatively short-lived and of small areal extent, except for frontal systems. Weather stations are about 100 miles apart for surface observations and 300 miles for upper air data. The size of the disturbances which appear in the analysis of data is consequently of the order of several hundred miles. From this, local weather is forecast on the basis of experience, physical evidence, and statistical relationships. Forecasts are improved if information on a small scale, such as that obtained from radar, is available.

Micro- and meso-scale systems are predicted through extrapolation from synoptic patterns, and little prediction capability is claimed. Major problems are mathematical and theoretical difficulties in developing predictive models for small scale disturbances, the necessary accuracy and number of observations, and the short time available for processing interpretation and dissemination of results (National Academy of Sciences/National Research Council, 1971).

Thunderstorms and squall lines are difficult to forecast before they form, and efforts are directed toward their detection, short-term forecast of motion, and dissemination of warning. Squall lines and, to a greater degree, fronts are forecast with steadily increasing accuracy as they approach. However, the accuracy of wind forecasts is generally less than 80%, which is poor compared to that for temperature forecasts, and decreases with increasing wind speed. The accuracy is also difficult to determine because of the large spatial variability in wind speed.

For downslope windstorms, statistical techniques have been used to estimate the probability of high winds from certain upper air and surface parameters. It is generally found, however, that although downslope winds can be predicted with some accuracy because the general synoptic patterns necessary for their development are known, it is extremely difficult to distinguish between the occasional really destructive storm and the more frequent milder variety (Sangster, 1972; Williams, 1952; Sergius, 1952). Sangster concluded that, "it would seem doubtful that appreciable improvement by a statistically-derived objective scheme over the skill shown by the technique of this memorandum can be achieved without additional insight based on experience or physical-dynamical reasoning" (1972, p. 21).

The benefits to be derived from an adequate forecast and warning system are high. An estimated 25% reduction of the losses could possibly be achieved, considering that much damage is done by flying debris and to unprotected windows.

Tsunami*

Determination of tsunami risk along coastal and island communities in the United States is essential in the preparation of warning decisions and actions. At present the State of California Division of Mines and Geology is attempting to delineate the tsunami hazard in California. The U. S. Army Corps of Engineers is beginning studies with a view toward assessment of the tsunami hazard over extended periods of time, and also the design of protective structures to reduce damage.

The necessary linkages between the generation of a tsunami and the mobilization of state and local warning systems are facilities for detecting the tsunami and communicating this information to all threatened points for dissemination to officials, and then residents. Basically the current system consists of a Pacific-wide Tsunami Warning System, supported by the Federal government, with linkages with Japan, U. S. S. R., and 13 other countries. This system transmits information on tsunamis

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*Sea waves generated by submarine disturbances--often associated with earthquake--whose crests may reach great heights when they encounter land.

to the various states, which generally use the National Warning System (NAWAS) for receipt and dissemination of the information to county and local officials. It is composed of 22 seismographs and 47 tide stations.

In most cases, the detection of an earthquake gives the first clue to the possibility of a tsunami. The ability to detect a tsunami and calculate its speed makes it possible to determine its estimated time of arrival (although intensity and expected wave height are still unpredictable) for various points distant from its origin. However, only a small proportion of even fairly strong earthquakes are accompanied by tsunamis of a noticeable magnitude.

The monograph Earthquake Engineering Research (National Academy of Sciences, 1969, p. 237) reports that, "Earthquakes of Richter magnitude 6.5 or greater are sometimes accompanied by tsunamis." This estimate apparently was based on studies by K. Iida (1963). On the basis of available information, one might offer the following conclusion: about 7% of Pacific basin submarine earthquakes which have Richter magnitude 6.5 or greater may be accompanied by tsunamis of appreciable destructive power; of these tsunamis, about 25% may actually result in destruction. The combination of these percentages results in a figure of 1.5-2%.

Communication channels connect all sensing stations and the Tsunami Warning Center (TWC) which is located in Honolulu, Hawaii.

> Within a few minutes after an earthquake occurs, seismologists analyze seismograms and report information to the TWC, where the location and magnitude of the earthquake are determined. If a possible tsunami is indicated, a tsunami watch is established and tide stations, outward from the epicenter, are queried for confirming water-wave recordings. When positive wave action is reported by a tide station, the Honolulu center issues a tsunami warning, which includes any reported wave heights and the expected times of arrival for threatened areas (OEP, 1972 Volume 1, p. 93).

Such watches and warnings are distributed to local civil defense or other responsible agencies which alert public warning agencies who have full responsibility for issuing warnings to the general public.

The devastation caused by tsunamis accompanying the Alaska earthquake of 1964 led to the institution of the Alaska Regional Tsunami Warning System in 1967. This system is intended to detect, locate, and calculate the magnitude of earthquakes in that region as quickly as possible, and to issue tsunami watch and warning messages through the use of initial seismic data. The time required to secure verifying oceanographic data is too great to permit timely warning of communities near the epicenter, so their warnings are based on seismic data only. As data from the tide gauges become available, the decision can be made on the need to alert towns and cities more distant from the epicenter. Determination of the need for watch and warning messages to Alaska for tsunamis of distant origin remains the responsibility of the Honolulu Observatory (Haas and Trainer, 1973, pp. 1-2).

Avalanche

The prediction or forecasting of specific avalanche occurrences is not at present a well-developed technique. LaChapelle (1966) has developed a statistical approach for determining the probability of avalanche damage to buildings at specific sites; however, this technique has nothing to do with prediction and forecasting in the usual use of the terms.

In general, it might be said that the appearance of certain geomorphic and vegetational indices are evidence of avalanche paths. In the absence of historical records of avalanche occurrences, certain observational methods can be used to determine the frequency, magnitude, and extent of avalanching. Three methods exemplify techniques in determining frequency.

Core samples of trees that were destroyed or damaged by some past avalanche can be taken, and estimates made of the last run on the site. When an avalanche path is not clearly defined, other evidence is assessed. In Colorado, the occurrence of aspen indicates ecological disturbance on a slope--by forest fire, logging, landslides, or avalanches. The cause and the year of occurrence can often be determined by closer examination in the field. Certain trees may indicate restrained or contorted growth patterns or injury. The position of scars, trimmed branches, and tops pointing downward or upward may indicate the direction and crude magnitude of snow movements, in the absence of other natural causes (Potter, 1969).

The general nature of the slope, its orientation, and a process of elimination of other disturbance patterns (man-made, mass-wasting, and fires) may also be used to identify and map avalanche paths. The use of existing high-altitude technology (ERTS-1 satellites maintained by the National Aeronautics and Space Administration) also lowers the cost of this determination (Madole, 1973). Avalanche tongues of rock debris projecting fan-like as a series of successive depositions may be seen from the air. It is believed that a tongue may represent long periods of slow accumulation, dating since Pleistocene times (Potter, 1969). Avalanche debris deposited at the foot of slopes is a certain sign of activity. "Trim lines" in the forest cover which separate new growth from old may be used to estimate avalanche frequency (Potter, 1969).

For the purpose of the short-term prediction of specific avalanche occurrences, two avalanche types may be defined, (1) loose snow, and (2) slab.

Forecasts of loose snow avalanches are based on ten snow condition factors which are ranked individually in terms of their contribution to the hazard: old snow depth, conditions of the base, new snow depth, new snow type, new snow density, snowfall intensity, precipitation intensity and Atwater number, settlement, wind, and temperature.

Slab avalanches are forecast differently. For these, sample pits in the snow are routinely dug in known avalanche areas controlled by the Forest Service. Periodic pit inspections are made to determine the nature of snow conditions by observation. Visual and tactile discriminations are made of the density and depth of the various snow layers and the presence of weak layers. The potential sliding layer among several weak layers is usually hard to determine. Temperatures of the layers are taken at regular intervals to determine gradients, or the presence of isothermal conditions.

Snow resistance is measured directly by means of a "ram penetrometer" (rammsonde), an instrument that penetrates the snow when a weight is released. For each degree of penetration, the amount of force can be ascertained, and strength determined for the layers. In predicting the release of a slab, hazard warnings are issued in a given region--as is also the case for direct-action warnings.

Test skiing is also part of snow stability evaluation. Ski patrolmen or rangers ski smaller slopes to assess how bigger slopes may respond. The nature of the cracks made by skis on such test runs gives some indication of stability.

At present the Forest Service of the U. S. Department of Agriculture has the responsibility to evaluate the avalanche hazard, but only in areas of heavy human use. State highway departments, mining companies, and several universities involved with snow research cooperate with the Forest Service in an effort to predict avalanches at mine sites, railroads, and highways. No predictions are currently made for less used areas; under extreme conditions, the U. S. Forest Service prepares avalanche warnings for back country areas which are issued through the National Weather Service.

The Forest Service is presently collecting weather, snow, and avalanche data in 12 western states at 42 specific locations in an attempt to develop an "avalanche hazard rating index." It is hoped that when completed, the index could be used in conjunction with weather forecasts to provide an avalanche warning service for many localities in the western United States.

Coastal Erosion

Since current coastal erosion warnings are a function of expected high water levels, they provide an oversimplified and inadequate summary of likely shoreline recessions. Issued from the National Weather Service forecasting centers along the coasts of the United States, they are derived by measuring differences between tide gauge readings and expected water levels at a given point in time. These figures provide qualitative indications that accelerated erosion is likely to affect beaches, dunes, bluffs, and other vulnerable backshore landforms on exposed coasts. Local Weather Service offices have limited responsibility for issuing warnings when unique conditions, which might go undetected by the forecasting centers, are reported. Warnings usually give a minimum of 6-12 hours advance notice of impending accelerated erosion.

Warnings are transmitted over the NOAA National Weather Wire Service and the NOAA VHF/FM Radio Transmission Service to organizations who own receiving equipment. These include national news services, newspapers, TV and radio stations, state police, civil defense, and other public agencies. If it is thought that forecast storm surge conditions will be exceptionally severe, warning statements are accompanied by advice to occupants of affected areas. This information is usually not provided in cases of erosion unassociated with flooding or other likely storm damage.

Unless accompanied by severe storms, erosion poses little direct threat to personal safety. Maps of storm surge inundations and evacuation routes, prepared by NOAA and the U. S. Department of Housing and Urban

Development, can be used to advantage by persons wishing to remove erosion-threatened property to safer locations.

Past evidence indicates that local erosion patterns are extremely irregular, with apparently identical adjacent properties suffering contrasting damages. Abrupt reversals of temporal erosion trends are also common.

Erosion warnings suffer from shortcomings similar to the flood warnings issued by the National Weather Service. The National Oceanic and Atmospheric Administration Weather Wire Service is not yet available on a national basis; many potential beneficiaries do not subscribe to the service; and dissemination of warnings is often slow and does not reach the public directly. Warnings are frequently misinterpreted or ignored by local residents or mass media channels. No attempts have been made to develop a system for forecasting erosion due to starvation processes associated with variations in the supply of littoral sediments.

With the exception of data on cyclical water level fluctuations in the Great Lakes, there is a strategic information gap between warnings of imminent shore damage and geological evidence of coastline trends over hundreds or thousands of years. This dichotomy is mirrored in the contrasting attitudes of engineers and natural scientists to the selection of erosion-control adjustments (McHarg, 1969). Developing forecasts for middle-range coastal change is a potentially fruitful research field.

Drought

Two schools of thought exist on drought predictability: some investigators believe that drought is a random thing; others believe that drought may occur in cycles. Superimposed upon random or cyclic changes in climate are long-term trends such as the current cooling trend.

If one believes that climatic change is a random process, accurate forecasting is impossible and an appropriate approach to the problem is through statistical probabilities. By determining the frequency with which droughts might be expected, as Friedman (1957) did for south and southwest Texas, agricultural practices and urban development may be planned with at least some degree of confidence. However, the study of past changes in precipitation is somewhat restricted by the limited availability of records exceeding 50 years duration. Indirect evidence has been used to extend the data base, although interpretation is somewhat problematic. For instance, Fritts (1965) has used dendroclimatic analysis to map cool, moist and warm, dry areas in the western United States since 1500.

Beyond the problems of exact statistical calculations, however, it may be possible to state with some degree of confidence what the likelihood is of a major drought striking the Great Plains region. Borchert (1971) has shown that extensive droughts occurred with midpoints on the time-scale at 1892, 1912, 1934 and 1953; some evidence exists for an earlier drought in the 1860's. These data suggest that major droughts can be expected to occur about once every 20 years on the average.

If one believes in non-random variations, prediction is simply an extrapolation into the future. On the basis of an 80-year cycle, Willett (in 1951) predicted no major drought in the western United States before 1970-1980, more possibly between 2000 and 2020. Using the cycle proposed by Thomas (1962), the next major Great Plains drought period should have occurred in 1969 or 1970. Borchert (1971) not only predicts another dust bowl in the 1970's, but also suggests alternate windy and less windy drought periods. A more intricate approach is the ultra long-range weather forecast by Krick (1972) which is based on a combination of several hundred different atmospheric pressure patterns with different frequencies. Successful prediction for periods up to five years is claimed. Mitchell (1964), after severely criticizing cycle hunters, agreed to the existence of two periodicities (the biennial oscillation and the 14.765-day lunar influenced cycle), but commented that neither accounts for enough variation to be worth incorporating into routine procedures of prediction. Whether or not this conclusion is correct still needs to be tested.

Other non-random elements that could be used for predictive purpose are long-term trends, such as the current cooling trend, and persistence. Once a drought pattern is established, there appears to be a tendency toward persistence. Namias (1963) pointed out that warm, dry springs in the Great Plains tend to be followed by warm, dry summers, and suggested that when the Southern Plains have been dominated in spring by a very dry regime (an upper level anticyclone), the soil dessicates and, in turn, favors the persistence of the anticyclone. There is a tendency in the area affected to increasing duration of the drought.

Current dynamic numerical models are incapable of forecasting beyond two to three weeks because of a lack of an adequate observational network on a worldwide basis, and deficiencies in the physical formulation of the prediction models. Various climatic models exist which are capable of depicting present-day climate; they have generally been used in an attempt to understand past climatic changes.

Very little is being done with respect to long-term prediction, partly because much work still needs to be done on the development of adequate models and partly because the causes of climatic change and the resulting changes in weather and climate patterns have not yet been sufficiently identified. Furthermore, factors such as the world-wide level of volcanic activity cannot be predicted presently. Last but not least, the possible role of man cannot be overlooked. Man's effect on the amount and type of atmospheric contaminants and the implications with respect to climatic change have been widely discussed (Bryson and Baerreis, 1967; Davitaya, 1969; Study of Critical Environmental Problems, 1970; Study of Man's Impact on Climate, 1971). Borchert (1971) pointed out that a non-occurrence of the drought predicted for the 1970's (based on a 20-year cycle) could be interpreted to mean that human use of the earth has now significantly modified the atmospheric circulation, rather than as a disproval of climatic cycles.

Earthquake

Earthquakes strike essentially without natural warning. They are felt no more than a few seconds or minutes, although there may be foreshocks and aftershocks spread over months. The time problem of warning is vastly different for earthquakes compared with that for hurricanes, floods and distantly generated tsunamis, and even significantly different when compared to tornadoes and flash floods.

At this point a distinction between prediction and forecast must be made. Prediction may be defined as the evaluation of the probability of occurrence of an earthquake of given magnitude in a seismically active area in some number of years. However, it is the forecast of the specific time and place of occurrence and magnitude of an earthquake, including the accuracy of that forecast, that is the necessary prerequisite to an earthquake warning system. Forecast is relevant not only for the occurrence of an earthquake, but also for aftershocks. The latter use of forecast would be important to decision-making concerning the reoccupation of buildings after an earthquake.

Considerable study has been devoted by seismologists to theory and instrumentation for earthquake forecasting. At present, American, Japanese, and Russian seismologists are independently engaged in research on different methods. While there are still differences of view regarding the feasibility of earthquake forecasting (OEP, Volume 1, 1972, p. 85), there seems to be more optimism now than even one year ago. Universities, the National Academy of Sciences, the National Science Foundation, and the Federal Disaster Assistance Administration are now taking actions which suggest the anticipation of a breakthrough within years rather than decades.

In this connection, one of the recommendations of the Committee on the Alaska Earthquake (1969, pp. 7-8) is especially interesting:

> Studies are needed to make earthquake forecasting and hazard evaluation practicable; not only the feasibility but also the socioeconomic implications of such forecasting need to be studied.
>
> At the same time that means of forecasting earthquakes are sought, research should be directed to the probable economic, political, and social consequences of more accurate earthquake forecasting. Forecasting would be welcomed by scientists and engineers, but for the general public in a seismic area it is not clear whether the ability to forecast earthquakes would solve more problems than it would create. For example, a recent probabilistic earthquake warning or forecast for an area in Japan is said to have resulted in great tension and damage to the local economy.

Forecasting, once proven reliable and accepted by the public, would be valuable in reducing casualties, saving easily moved property, and preventing losses from some of the secondary effects of earthquakes such as fire. Whether or not reliable forecasting will be realized may be debatable; whatever the conclusion, it seems questionable to continue research for forecast capability without researching the behavioral aspects associated with forecasts. Specifically, what will be done with a forecast and what will be its social consequences? False alarms or inaccurate forecasting may indeed create more problems than those which already exist.

Constraints to the adoption of forecast systems are numerous. Decision-makers may not want the responsibility of issuing a false alarm. Evacuation of an entire area may be infeasible without extensive planning. The economic costs of temporarily "shutting down" a city may exceed the cost of the earthquake.

Frost

Forecasting advection frost is based on the analysis of the general weather situation, and consequent predicting of the movement of the air masses and modification of their temperature characteristics as they move across the country. Forecasting radiation frost is much more difficult because of the very localized nature of the hazard. Only a warning of potential danger can be given; this information must be interpreted by the farmer in terms of stage of crop development and topography (Critchfield, 1960).

The Agricultural Weather Service and the Fruit-Frost Weather Service provide frost warnings to selected areas of the country. Many of these areas correspond with intensive deciduous and citrus fruit growing locations. Field crops, such as cotton, may also receive significant levels of warnings from these services.

Areas not covered by the Agricultural Weather Service or the Fruit-Frost Weather Service may receive warnings from the National Weather Service, as part of the general forecast service. This arrangement may not be satisfactory, however. Since all important meteorological parameters are not covered, the forecast parameters are not translated into their likely effects on agriculture, and adequate forecasts are not available due to the lack of special agricultural observations (OEP, 1972, Volume 1).

Currently, the U. S. Department of Agriculture and the National Weather Service are implementing plans to expand the Agricultural Weather Service. Both the services provided and the number of areas covered are being enlarged. Planning information for both the short and long-run will be provided, as well as certain specialized services.

Priorities for implementing the plan in states not presently serviced have been based upon a weighted average of cash receipts per acre and the proportional farm population. The first phase of the implementation plan has been completed (OEP, 1972, Volume 1).

Hail

The conditions under which hailstorms occur are fairly well known, and forecasts of thunderstorms "probably with hail" can often be given as much as 24 hours in advance, and certainly a few hours in advance. However, these forecasts will be for fairly large areas (several thousand or more square miles), while the normal hailstorm is of small areal extent (two to five miles in diameter). Individual hailswaths and hail intensities cannot be forecast with any demonstrable skill at this time.

Radar represents a new means for identifying and tracking hailstorms and describing some of their characteristics (hailstone size) in quantitative terms. Short range (0-3 hours) forecasts and warnings of hailstorms could be formulated on the basis of radar data. The establishment of such a system would involve certain changes in both the present radar network and the forecasting program within the National Weather Service.

Even if hailstorm warnings were available, the range of protective actions available to the individual is severely limited. With regard to most crops, there is little if anything the farmer can do. In the case of property such as aircraft and automobiles, even a few minutes warning might be beneficial. However, no hail-specific research seems warranted at this time.

Landslide

The occurrence of past earthslide events is a basis for predicting hazardous areas; in regional terms, an evaluation of future occurrences must, in part, be based upon past events.

In terms of utility, a distinction may be made between (1) predictive investigations that lead to the adoption of protective structures on a more short-term and micro-planning scale, which can include landslide warning; and (2) predictive investigations that lead to the adoption of measures, such as land use management, on a more long-term and regional scale. Although prediction in the former context has been developing for decades (Ritchie, 1958; Ta Liang and Belcher, 1958; Philbrick and Cleaves, 1958; and Baker and Yoder, 1958), its application for more long-term regional planning is new (Morton and Streitz, 1967; Cleveland, 1967; Nilsen and Brabb, 1973).

1. Site-Specific Surveys

Traditional methods for identifying and investigating specific landslides and their stability (actual or potential) are outlined in Eckel (1958, chapters 5, 6, 7 and 9). It can be generally said that the use of combinations of well-developed methods allows the engineer to identify and ascertain the cause, mechanism, and potential movement of past, present, and future landslides for the principal purpose of assessing the potential for applying protective works.

Responsibility for carrying out these investigations falls on either the user agencies themselves (such as the Federal Highways Administration and the geologic divisions of some state and large local authorities), or on private consulting agencies. The predictive findings are utilized by a range of user agencies, both public and private, at Federal, state, and local levels. The capacity of this type of prediction to reduce losses depends on many factors, as does the adjustment's cost. These factors include the nature of the landslide problem--both cause and extent--and the type of human activity. In addition, the intensity of the investigation will vary with the degree of actual or potential losses involved, i.e., it is a function of the importance of the land usage. To predict the stability of a slow-moving large landslide mass in a highly valued area (the Ventura oil-fields, for example), may cost many thousands of dollars, whereas for a small mass on a single construction site the costs could be quite small.

Methods are being developed to help forecast the immediate failure of the potential landslide mass. These include the use of automatic sensing extensometers that can indicate when instability approaches 100%. Developed at the Norwegian Geotechnical Institute, it is not known to what extent they have been adopted in the United States, by whom, and at what cost and efficiency.

2. Regional Forecasting

Until recently, reports and maps neglected to show the distributions and contributory causes of landslides; however, the tools necessary for regional landslide predictions have been available for decades, and the use of old techniques for new and different purposes has required the development of new methodological procedures.

One of the first regional landslide prediction methods was tnat developed by Blanc and Cleveland (1968) for the California Division of Mines and Geology (CDMG). Its theoretical experimental aspects were later refined by Cleveland in a report prepared for the Federal Insurance Administration (of the U. S. Department of Housing and Urban Development) in 1971, as part of a cooperative agreement between CDMG and FIA. A field test for that report was conducted by Evans, *et al.* (1971) in southern Ventura County, California (California Division of Mines and Geology, 1972).

There, regional landslide prediction was based upon theoretical models (the study of natural landslide processes) and empirical methods (the study of existing landslide distributions). In analyzing the risk for over 1,000 square miles of Ventura County, three predictive factors were applied: (1) background factors, including critical angle of natural slope, vegetation type, density, and distribution, soil types and distributions, type of rocks, and bedrock mudslide distribution; (2) the available energy, including intensity and amount of precipitation, fire distribution and potential, and marine erosion; and (3) some special factors, including presence and absence of swelling clays which retain water, adverse geologic structures, such as bedding planes dipping parallel to the natural slope, highly fractured or faulted zones, and high ground water tables.

The 1,015 square mile area was zoned as high risk (69%), intermediate risk (6%), and low risk (25%) (California Division of Mines and Geology, 1972, p. 136).

Recently a landslide susceptibility map was produced for San Mateo County, California (Brabb, *et al.*, 1972). The method utilizes data on (1) the distribution of geologic map units (both bedrock and surface deposits), (2) historical occurrences of landslides, and (3) the slope classes for each of the foregoing areas. It estimates the gross strength of the rock by comparing the surface extent of the rock unit with the percent that has failed by landslide. The advantages of this technique are that it is transferable to another area; it does not depend on extensive field experience; and the calculations can be done by computer.

The use of remote sensing data from the National Aeronautics and Space Administration's ERTS-1 satellite by investigators at the University of Colorado's Institute for Arctic and Alpine Research (INSTAAR) extends traditional air photo analysis in a way which allows rapid and approximate coverage of the most vulnerable landslide-avalanche areas in the Colorado Rocky Mountain region, particularly Vail, Telluride, Silverton, and Boulder County. More accurate and detailed procedures similar to those used in California are still a necessary aspect of INSTAAR's research into geologic and landslide hazards, although their project is still at the recognition of landslide stage.

Drawing upon the Blanc and Cleveland (1968) method, investigators with the U. S. Geological Survey have developed landslide susceptibility maps which show the average susceptibility of slope-material units to mass movement in the San Francisco Bay region (Nilsen and Brabb, 1973). These landslide susceptibility maps are the amalgam of a series of geologic, slope, and landslide distributional studies.

From the above, we can see that the responsibility for research and application of regional landslide prediction has been at the Federal level, with cooperation from state (as in Colorado and California) and local agencies (as in San Francisco). Since it is a new form of adjustment, its efficiency is yet to be tested, although intuitively it must form a basic component of the urban and related planning that is being designed to help curb environmentally hazardous development.

Detailing the costs of the various elements involved in development and applying regional prediction would be difficult and unnecessary for our needs. More generally we can say that the U. S. Geological Survey's landslide susceptibility map for San Mateo County, San Francisco Bay Region (Brabb, *et al.*, 1972) cost $150,000 to produce, that is, $330 per square mile. The CDMG's southern Ventura County landslide risk analysis cost about $38,000, or $38.00 per square mile.

Studies of landslide origin done in more detail, such as in San Clemente (Blanc and Cleveland, 1968) and in Palos Verdes Hills (Cleveland, 1967), are more costly. Done at 1" = 1,584' and 1" = 500' respectively, the cost for each map was approximately $1000 per square mile.

Lightning

Forecasts of thunderstorms can be given as much as 24 hours in advance since the general conditions necessary for their development are quite well understood. Forecasts will, however, cover large areas; several hundreds or thousands of square miles may be involved. Individual thunderstorms presently cannot be predicted, although once they have developed identification and tracking by radar is possible. Sferic detectors are relatively inexpensive devices for detecting the occurrence of lightning storms.

There are at least two systems which warn of the thunderstorm and the possible accompanying fire hazard. The National Severe Storms Forecast Center (NWS) at Kansas City is equipped to issue severe weather warnings, as mentioned earlier in the report. Sophisticated detection equipment is part of this system, including current trends toward location of remote fires with infrared devices housed in weather satellites, and radar networks which are currently being improved.

Thunderstorm forecasts are of extreme importance with respect to forest fires since the likelihood of fire detection, the readiness to suppress the fire, and the tactics of suppression action are influenced by the forecast. Because of this the National Oceanic and Atmospheric Administration has established the National Fire Weather Service which disseminates fire weather forecasts, warnings, and advisories to fire control and forest management agencies.

The U. S. Forest Service is also aided by more general forecasts that determine the potential fire danger conditions in the event of man-made or lightning fires. Such warnings are based on several factors including forest litter and meteorological considerations. The Fire Weather Service is an important tool in anticipating fire danger.

Urban Snow

Accurate and timely prediction of snowstorms enables dissemination of a warning. Provided that snow warnings are promptly and accurately relayed, snow fighting processes and preparations by motorists and individuals are begun. Existing snow emergency regulations are also put into effect. Adjustments are adopted which can reduce exposure to adverse travel conditions and maximize the effectiveness of vehicles and snow-fighting personnel. Organizations such as hospitals are able to institute plans that will provide a full staff throughout the snowstorm.

In addition to dissemination of forecasts, the ability of persons who receive warnings to interpret a forecast, and the accuracy of predictions are constraints inhibiting the effectiveness of this adjustment to snow. Private weather forecasts supplement National Weather Service forecasts of snow phenomena.

There is disagreement on how accurate snow forecasts are, and whether accuracy is improving. Spiegler (1970) points out that snow prediction is a particularly difficult task because of the number of variables involved: the extreme precision needed regarding temperature and moisture content; and the rapid but erratic movement of storm systems. Nonetheless, he predicts improving accuracy. Cooley and Derouin (1972) give figures showing gradually improving accuracy of National Weather Service forecasts. They note, however, that for the nation in 1971-72, in terms of 12-hour warnings of four inches or more, only about 30% of the area (in square degrees of latitude) for which snow was predicted actually received the forecast amount. Friedman (1958) noted the large variability of amount of snowfall even within a single snowstorm and city. City officials can usually obtain more accurate information based on shorter warning periods and multiple information sources (Baumann and Russell, 1971; Foster, 1970).

Volcano

Long-range accurate forecasts of volcanic eruptions would be useful in preventing monetary losses and loss of life. As it now stands, the state of the art in eruption prediction is as variable as volcanoes themselves. Some volcanoes are able to be predicted, as in Hawaii, where certain seismic phenomena and land deformations may foretell the coming of an eruption with relative reliability. However, some long quiescent volcano may suddenly explode without previously displaying any observed signs of what was to come. Many of the methods to be discussed below can be employed effectively only at volcanoes which display particular kinds of behavior favorable for their use.

The seismograph is by far the most common tool of prediction used today. At many volcanoes, such as in Hawaii, the close association between earthquakes and volcanic eruptions has long been recognized; observations have shown that prior to an eruption, the frequency of tremors increases and the focal depth of the tremors decreases. This particular seismic behavior has, in some instances, given warning of an impending eruption months in advance. Often, the site of unusual swarms of earthquakes may indicate where lava will break out (Ollier, 1969; Waesche and Peck, 1966).

As magma moves upwards towards the orifice of a volcano, the pressure exerted may cause a swelling of the summit. It is possible to detect this swelling (or inflation) of the volcano, as at Kilauea, with a tiltmeter, an instrument which records the changing tilt of the ground as a result of the swelling. A geodimeter also is used to detect the same phenomenon, but by measuring the change in horizontal distance across the summit of the volcano instead of the tilt of the ground (Waesche and Peck, 1966). Waesche and Peck have noted the limitation of prediction from summit inflation: "unfortunately, the rate of inflation is not constant, and the level of tilt is not the same at each eruption; consequently, an exact prediction is not yet possible" (1966).

The upward flow of magma just prior to an eruption can, in some instances, produce geomagnetic variations in the vicinity of the volcano.

This particular characteristic has been discovered on Oshima Island, Japan, where seismic measurements have proved unreliable in predicting major eruptions. Observations and records taken during the early eruptive cycle of Oshima showed that the local magnetic dip decreased progressively up to the time of the major lava eruption of 1950-51 (McBirney, 1966; Macdonald, 1972).

Although only at experimental stages, comparison of infrared photos taken at regular intervals may possibly lead to prediction by detecting subsurface temperature increases associated with increased volcanic activity prior to eruption (Macdonald, 1972).

Crater lakes, hot springs, and fumaroles often show increase in temperature, or unusual changes in gas composition before an eruption. The exact nature or interpretations of these changes, however, can only be determined in light of lengthy studies of the specific volcano concerned, and even then the reliability of prediction is questionable. At present little use of this method exists, but future work may prove the method valuable for volcano predictions (Ollier, 1969; Macdonald, 1972).

Any unusual activity displayed by a volcano might indicate an upcoming eruption. Earthquakes, puffs of steam, unusually active fumaroles or hot springs, and even unusual behavior of wildlife and domestic animals have been known to precede major eruptions. Threatening mudflow conditions can often be recognized by trained geologists, although attempts at predicting the movement of them have so far been ineffective (McBirney, 1966).

The only examples in the United States of successful predictions of volcanic eruptions are in Hawaii. The active state of the volcanoes has made it possible to evaluate different techniques through numerous cycles of activity. The Hawaiian Volcano Observatory (HVO) has been closely observing and monitoring the Hawaiian volcanoes since 1912. The HVO has 33 seismic stations and 35 tilt stations. With the geodimeter, the HVO staff monitors the length of some 400 lines from about 100 established stations (Peterson, 1972). The HVO has been able to predict several eruptions of Mauna Loa and Kilauea. One of the best predictions to date was for the 1942 eruption of Mauna Loa (Macdonald, 1972).

The volcanoes of the Cascades and Alaska, on the other hand, do not have the predictive advantages of the Hawaiian volcanoes, and it is these volcanoes which are potentially the most dangerous to lives. Even if the prediction and warning of an impending eruption were possible, the nature and magnitude of that eruption would be unknown. The possibilities for observing and monitoring the Cascade or Alaska volcanoes in a manner as detailed as that being done by the Hawaiin Volcano Observatory in Hawaii are slim. There are too many volcanoes, and they erupt too infrequently. Finding justification for the spending of the necessary funds and effort would be difficult. McBirney (1966), however, has noted that it would be valuable and feasible to utilize inexpensive seismographs, along with more detailed geologic evaluation of each volcano by small groups of trained persons who could monitor a whole chain of volcanoes.

At present, the National Aeronautics and Space Administration is integrating volcano investigations into the ERTS and Skylab Programs. The investigations involve the integration of observations from space with data from emplaced instrumentation at selected volcano sites, the goal being a multifaceted understanding of volcanic eruptions and of phenomena which improve the ability to predict eruptions (National Aeronautic and Space Administration, 1972). Several Alaskan and Cascade volcanoes are included in the project.

Monitoring the Weather

Many of the hazards with which this report is concerned (drought, flood, frost, hail, hurricane, tornado, urban snow, and wind) are weather-related. Because warning for each may begin with the same environmental monitoring and hazard detection agencies, a general review of how the weather is monitored is warranted.

1. The Components Involved

At the broadest level, five agencies are involved in weather monitoring activities: the National Weather Service (NWS); the National Environmental Satellite Service (NESS); the Air Weather Service; the U. S. Navy; and the Federal Aviation Administration (FAA).

a. The National Weather Service

The NWS has the responsibility to provide a severe local storm warning service for the entire country. Its formal tasks are: (1) conducting basic surface, upper air, and radar observations; (2) making additional observations when necessary, and making reports of all observations available by teletype to all agencies requesting information; (3) conducting basic analyses and preparation of forecast charts at the National Meteorological Center; (4) disseminating severe weather watch bulletins, radar facsimile charts, and hourly radar summaries to anyone concerned, through the National Severe Storms Forecast Center; (5) disseminating local warnings to communities through Weather Service Forecast Offices and Weather Service Offices; (6) disseminating in-flight weather advisories through Weather Service Forecast Offices Aviation units; and (7) the collecting and relaying pilot reports.

The National Meteorological Center is the central data processing center responsible for the issuance of material which would aid in alerting the National Severe Storm Forecast Center and Weather Service Forecast Offices to situations which would require the issuance of weather watches. The National Severe Storms Forecast Center, through its Severe Local Storm Unit, has the responsibility for issuing and canceling such watches, as well as the preparation of essential material for the Severe Local Storms Warning Service. The actual issuance of watches is dependent on specific criteria. For wind, hail, and thunderstorm forecasts to be issued, winds of sustained speeds or gusts of 50 knots or more must exist, or hail at least 3/4 inch in diameter must be present at the surface. In the case of tornadoes, forecasts which mention tornadoes also include severe thunderstorm activity. Distances from reference points are required information in tornado forecasts.

Public tornado watches are not issued for areas for which the National Hurricane Center or a Hurricane Warning Office is issuing advisories or bulletins. In these instances, the appropriate information is contained in those advisories or bulletins.

It is the function of the Radar Analysis and Development Unit to prepare Radar Facsimile Charts, and to transmit them to the National Severe Storms Forecast Center via the National Weather Facsimile Network. Such charts are prepared on the hour. Supplementing this network are the military weather service radars and the FAA radars in the intermountain area of the country.

The actual public warning responsibility is in the various local Weather Service Offices (WSO). Severe weather statements are issued on the development, existence, or past occurrence of severe weather. Severe weather warnings are issued by a local WSO at such times when conditions indicate threat for the office's area of responsibility. Each warning is identified as either a Severe Thunderstorm Warning Bulletin or a Tornado Warning Bulletin, when radar evidence or visual sightings identify, in the opinion of the official in charge, severe weather.

Weather Service Offices also issue clearing bulletins when the threat has ended.

The Weather Service Forecast Offices are charged with the issuance of Aviation Severe Weather Watch Bulletins, which are called Aviation In-Flight Weather Advisories. Issued as Significant Meteorological Information Statements, they are dispersed when any of the following criteria exist: (1) tornadoes; (2) thunderstorms (squall lines); (3) embedded thunderstorms; (4) 3/4 inch or greater in diameter hail; (5) extreme turbulence; or (6) severe icing.

b. The National Environmental Satellite Service

It is one of the functions of the NESS to operate a satellite system which provides the coverage of specified sections of the United States during the severe storm season. Data in the form of pictures is provided from NESS to various research facilities, as well as to NSSFC at Kansas City.

c. The Air Weather Service

The Air Weather Service functions to disperse weather warnings to the U. S. Army and U. S. Air Force throughout the world. Through the Offutt Air Force Base in Nebraska, it disperses warnings to units in the conterminous United States and 200 miles offshore.

Within the conterminous United States, USAF radar weather observations are collected by the Continental U. S. Meteorological IIA System (COMET), and are dispersed by the COMET IIB System. This system, divided into eight geographical areas, has a collecting and disseminating circuit for each area.

d. The Federal Aviation Administration

The FAA provides communication services in support of the Severe Local Storms Operations Program, Flight Service Station observations, tower surface observations, the distribution of Airmen's Meteorological Information, and the distribution of Significant Meteorological Information.

2. Weather Observation Systems

a. Radar

Data observed by the U. S. Synoptic Weather Radar Network are collected by RAWARC and COMET II. These data are routinely used by all offices of the NWS and the U. S. Department of Defense Weather Service. Specialized use of the data is made in the National Severe Storms Forecast Center and the Hurricane Warning Offices.

The U. S. Air Force, U. S. Navy, and National Weather Service also operate a number of non-network radar facilities. Used primarily for local forecasting and warning, these installations also provide selected information on severe storms. Aerospace Defense Command radar sites, which are able to detect weather echoes, provide supplementary reports when requested to do so.

At times when data from the United States Synoptic Weather Radar Network are either missing or appear to be in error, WSO's and/or the U. S. Air Force or U. S. Navy will be contacted by telephone to obtain additional data. The U. S. Department of Defense and the Federal Telecommunications System telephones are used for this purpose; however, commercial lines may be used if the former are unavailable.

b. Rawinsonde

At the 70 stations in the National Weather Service and Military Upper Air Network, rawinsonde observations are made two times a day (0000 and 1200). Data compiled from these observations are transmitted over the COMET II and Service C teletype systems in radiosonde code. Data obtained from special soundings which have been requested for specific severe weather events are transmitted by means of RAWARC.

c. Surface Observations

All available surface data are utilized to obtain the information needed for the analyses performed by the National Meteorological Center, the National Severe Storms Forecast Center, the Air Force Global Weather Central Office, Weather Service Forecast Offices, cooperating observing stations, Cooperative Hurricane Reporting Network, and the hydrologic observing network. The stations providing these data are (1) WSO's, (2) Automatic Meteorological Observing Stations, (3) Federal Aviation Administration weather reporting stations, (4) Supplementary Aviation Weather Reporting Stations, and (5) the U. S. Department of Defense weather reporting stations. Coded observational data are transmitted at scheduled intervals: hourly for aviation purposes; every three to six hours for synoptic map preparation; and daily for climatological purposes.

d. Federal Aviation Administration Pilot Reports

At present FAA Instrument Flight Rules require pilots to report any unforecast weather conditions encountered in flight. Distributed via teletype, information is dispersed regarding turbulence, icing, hail, and thunderstorms from Airline Meteorological Offices.

e. Satellites

The National Aeronautics and Space Administration (NASA) is responsible for developing satellite technology, developing and launching prototype spacecraft, and launching spacecraft for the NOAA satellite program. The National Environmental Satellite Service of NOAA operates and controls spacecraft in the operational satellite program, which includes meteorological satellite imagery. There are two types of satellites, polar orbiting and geostationary.

f. Nonmeteorological Agents

The National Weather Service uses observations of severe local storm activity (particularly tornadoes) from many nonmeteorological agents. Some examples of these are: local police departments; utility companies; road maintenance patrols; radio and television station mobile units; and citizen spotters. Received through a multitude of channels, these reports are dispersed to WSO's local safety agencies and the mass media.

g. Aircraft Reconnaissance

Daily U. S. Air Force Reconnaissance Flights are made in the Gulf of Mexico; observational data for the gulf are not obtained by other means. The "Gulf Echo Track" is flown once daily, and the data transmitted to the National Hurricane Center in Miami, Florida.

3. Organization-to-Organization Communication Systems

a. RAWARC

The National Weather Service internal teletypewriter system consists of five circuits and terminates at the National Severe Storms Forecast Center in Kansas City, Missouri. The Warning Coordination (RAWARC) has recently been completed and transmits hourly radar reports; special radar reports can be transmitted at any time the system is not in use. The RAWARC system operates to collect, collate, and disseminate radar reports and warning information among weather offices. Extension of RAWARC during Fiscal Year 1974 completed the network.

b. NWWS

The NOAA Weather Wire Service (NWWS) functions to transmit forecasts, watches, weather warnings, and meteorological data to the mass media for public broadcast. Relays made between states through State Relay Centers are coordinated in Washington, D. C., at the Overlay Relay Center. The NWWS is currently installed either completely or partially in 30 states. The NWS, having the prime entry into the system, plans to expand the system to all of the conterminous United States by the end of Fiscal Year 1978.

c. NAWAS

The National Warning System (NAWAS) is primarily designed to provide notification of a military attack upon the United States. However, under the Disaster Relief Act of 1970, NAWAS is authorized to provide warning to local officials of the imminent impact of some natural hazard agents.

Three protected Defense Civil Preparedness Administration (DCPA) National Warning Centers control NAWAS. NAWAS operates continuously and has 1,867 warning points throughout the country. Approximately 90% of the warning points are provided with emergency power for the operation of warning equipment. Connections have been installed or are planned for all NWS offices with county warning responsibility.

4. Public Warning Systems

a. Sirens

The existing DCPA-managed siren system is designed to be used in conjunction with NAWAS for the dissemination of an attack warning. However, the actual activation of sirens can be controlled at the local level. This means sirens are available for local use in natural disaster warnings. Expansion of the siren system is contingent upon the requirements of population growth, and relies on local matching funds with Federal funds through DCPA.

There is reason to believe that confusion about the meaning of the siren signal would be reduced if natural hazard warnings were sounded in distinctly unique sound patterns. The integration of the use of sirens for natural hazard warnings has great potential for alerting an endangered populace.

b. Recorded Telephone Announcements

Three types of systems are in current use for disseminating information via telephone on disaster agents such as hurricane and severe storms. The large volume WE6-1212 system can handle up to 1,000 calls simultaneously. Such systems have 30-second or less announcements and are provided by telephone companies as a public service. Nineteen cities currently have this service.

The low volume system of recorded announcements is operated by the NWS from its service offices. This system can handle up to ten calls simultaneously, and is used for local and specialized weather information.

The third type of recorded telephone announcement system provides abbreviated forecasts. Such systems contain approximately 1,000 prerecorded forecast and warning messages which are automatically programmed into the system upon receipt of coded messages from NWS forecast offices. These systems are installed and operated by telephone companies; funds for their operation are obtained by the sale of sponsored messages which are broadcast over the system.

The use of telephones to disperse information to persons beyond those who call for it has been studied to determine such a system's feasibility. The system would activate telephones in threatened areas and provide recorded warning messages automatically when phones were answered. This system would provide a great dispersal of threat messages to a populace with minimal constraints to its adoption by that populace. However, constraints to its adoption exist: prohibitive cost, political acceptability, and mechanical requirements.

c. VHF-FM Radio

The National Weather Service operates VHF-FM radio systems which continuously transmit weather forecast information and have a tone-alert capability. WSO's which are equipped with these systems transmit over a frequency of 162-55 MHz or 162.40 MHz. Their effective range covers a 40 to 60-mile radius. The number of such systems is limited. Current plans are to expand the network to 320 stations by 1979, and to provide nationwide coverage forming a Natural Disaster Warning (NADWARN) system.

d. Mass Media

It is only through voluntary cooperation that mass media (TV and radio) warnings are disseminated. Stations receive information primarily via the NWWS or the national wire services. Many stations rely upon VHF-FM and direct phone calls. The management of media stations, totally at its own option, decides whether or not to transmit the weather warnings, as well as the content of those messages.

e. Satellite Systems

At present NOAA and NASA are conducting investigations to determine the feasibility of communication satellites for use as a warning system. The requirements of the proposed Disaster Warning Satellite System (DWSS) would include: (1) a system for collecting data and feedback information upon which to base warning decisions; (2) a means for alerting the general public; (3) general weather forecast broadcasts; and (4) communications to and among Weather Service Forecast Offices, Weather Service Offices, National Warning Centers, River Forecast Centers, Weather Service Meteorological Observatories, and local areas.

To date, preliminary studies suggest that the application of satellite technology to disaster warning may be desirable and feasible.

f. EANS

Emergency Action Notification Signals (EANS) can be used by local radio and television stations to give listeners a warning. Used at the discretion of the individual media stations, but in accordance with rigid FCC regulations, signals can be broadcast when an urgent need exists to inform persons of existing dangerous weather conditions.

g. DIDS

The Decision Information Distribution System (DIDS) is currently being developed by the DCPA to provide a capability for the simultaneous nationwide issuance of attack warnings and local natural hazard warnings. If fully implemented, population coverage in the conterminous United States would be up to 99% for siren control, and up to 97% for voice messages. Present plans are for a minimum of 40,000 voice receivers, 12,000 voice plus teletype or tape, and 5,000 siren controls. A prototype DIDS transmitter has been constructed at Edgewood (Aberdeen), Maryland. It is now undergoing testing.

DIDS receivers can be located at national, state and local emergency operating centers; Federal and state agencies; national and local warning points; state adjutant and military headquarters locations; and radio and television stations. Receivers would be turned on and off remotely by DIDS. The rewards of the implementation of such a system are potentially great as a means of communication to individuals and organizations at the state, county, or local level.

Receivers for use by the general public are presently being developed and will be tested in a pilot community in 1975. The NWS has agreed to furnish operator control of this prototype transmission facility to provide for active local disaster warning services to the test community. The extent to which the public would purchase such receivers for home or office is dependent on their actual cost, effectiveness, and on whether individuals would see the receivers as invasions of privacy.

5. Other Means

The dissemination of warning to the general public in specific communities for specific pre-disaster events also involves the operation of local emergency organizations. For example, in flood disasters it is likely that police and fire departments canvass endangered areas of a community. Street loudspeakers and door-to-door means of warning dissemination by such units play a significant role in warning dissemination because such warnings are likely to be specific and personal to the recipient, and more likely to be followed by adaptive response.

CHAPTER IV

COMMUNITY PREPAREDNESS

Risk Delineation

The local delineation of hazard risk is a prerequisite to adequate warning preparedness. Risk definition is not only important to warning plans for predictable hazards, but also is the primary tool in mitigating the impact of hazard agents for which warning is not possible. Warnings can be specific to those in danger by defining safe areas, and by defining how to best reach those areas, if their content is based on information concerning which areas of a city are subject to hazards.

Risk delineation in a community can upgrade warnings by the establishment of specifics for the content of future warnings. The assessment and evaluation of potential disaster risk within a community must precede planning in order to fully determine planning requirements and resource priorities. In much the same way that monitoring the environment and detecting the impending impact of a hazard agent precedes warning, preparedness for such an event is preceded by an understanding of the hazard potential in a community. Warning preparedness with a base in risk delineation must be centered around a series of community-specific questions:

(1) What is the hazard?
(2) Where is it likely to occur?
(3) How frequently is it likely to occur?
(4) What is the range of magnitude likely to occur?
(5) What would constitute appropriate pre-impact action?
(6) Who should take that action?
(7) How should those persons be warned to perform that action?
(8) With what resources (personnel and technology) can warnings be given?
(9) What approach, method or procedure would be best used?
(10) Who would be involved?
(11) What will they do?
(12) How will they do it?
(13) How would the total warning effort be best coordinated?
(14) Who will pay for it?

Community preparedness is before-the-event organization of a community, usually based in the political structure of that community, for some eventual but undetermined event. It consists of plans and procedures for response to both the impending and actual impact of the hazard agent. Warning *is* based in preparedness, whether it be warning of the impending initial impact of the agent (the half-hour before a tornado), warning during impact (as in long-term flood), or warning after impact of secondary hazards (like fire).

Figure IV-1 is presented in an attempt to illustrate the roles of *risk delineation* and *preparedness* as they affect warning feasibility and efficacy in the evaluation-dissemination subsystem of a warning system. Figure IV-1 illustrates that: (1) technology determines whether or not a hazard's impact is predictable; (2) technology partially determines how warnings are disseminated; (3) technology determines how and to what extent risk can be determined for a hazard by area; (4) predictability determines whether a warning can or cannot be issued prior to impact; (5) predictability also determines the feasibility of risk determination; (6) risk determination is a prerequisite for complete preparedness; and (7) preparedness is vital for adequate warning.

An adequate definition of risk potential in a community will illuminate specific capabilities needed in a warning system.

Federal Planning Involvement*

At the present time, the Federal Disaster Assistance Administration has the responsibility for coordinating emergency planning (other than warning-related) at the national level. The Defense Civil Preparedness Agency has the responsibility for the development of a coordinated Federal program for preparedness assistance to local communities. According to the Federal Disaster Assistance Program Handbook (OEP, 1972a), state plans must be in accordance with Federal ones, and plans of political subdivisions within states must be in accordance with both Federal and state emergency plans and operations. In October, 1969, the Federal government began providing matching funds of as much as $250,000 for the development of state disaster plans. The Disaster Relief Act of

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*A more detailed discussion of the role of the Federal government in natural disasters may be found in the monograph on Relief and Rehabilitation in this series.

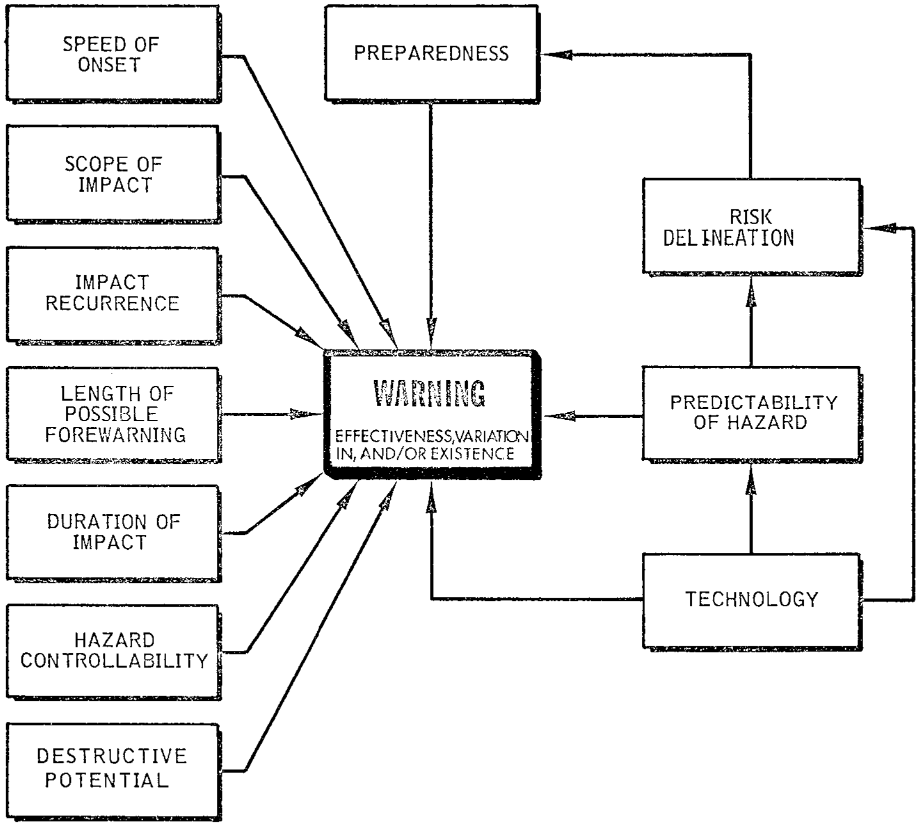

FIGURE IV-1 MAJOR VARIABLES AFFECTING WARNING

1974 (Public Law 93-288) provided 100% of Federal financing (up to $250,000) of state disaster preparedness programs. In addition, annual grants of $25,000 (on a 50-50 basis) are available for the updating of such plans.

Because of the major role DCPA has in preparedness planning and the parallel responsibilities of NOAA in natural disaster warnings, extensive NOAA/DCPA coordination has developed. A formal agreement has established standard procedures for interagency NOAA/DCPA coordination at the national and regional levels. At the present time NOAA assists in the development of preparedness programs carried out primarily through the field activities of the National Weather Service, which includes warning dissemination at the community level. In addition,

> hurricane preparedness specialists have been assigned to each Hurricane Warning Office to assist communities in organizing their preparedness efforts. Additional specialists are programmed for assignment to Weather Service Forecast Offices each year through 1978. These specialists emphasize the need for fast, reliable dissemination and adequate disaster plans as they work in close coordination with the DCPA On-Site Assistance effort; perform surveys to determine requirements for flash-alarm devices; assist communities in developing self-help flash flood warning systems; train tornado and severe storm spotters and organize reporting networks; participate in public education programs on the threats of each type of disaster and personal safety rules for each; and advise and assist local and state authorities in planning and establishing emergency procedures and facilities (National Oceanic and Atmospheric Administration, 1973, p. 83).

CHAPTER V

SOCIETAL FACTORS

The effects of technology and hazard-related social organization on the hazard potential of any one area do not exist independent of larger societal forces. These societal factors can affect hazard potential and, therefore research needs and priorities on adjustment to any hazard.

Population

Three trends have been identified in the size and distribution of population: (1) as the year 2000 is approached, the growth rate will level off; (2) regional migration patterns will continue--California, Arizona, Nevada, Colorado, Texas, and Florida are growth leaders, and the Northeast is losing population, with the exceptions of Delaware, Maryland, and New Jersey; and (3) rural-to-urban migration will continue, but at a slackened pace. In addition, most of the states which are leaders in net size growth are the same states that are above the national average in percent increase in urban population.

Increasing urbanization may be interpreted as increasing concentrations of population. Such trends need not reflect increases in overall vulnerability; however, by increases in the population of any one place, vulnerability to catastrophic disasters and their accompanying losses is increased. As a consequence, the growth leader areas of the country are increasing in general hazard vulnerability and in catastrophe potential; states losing population are experiencing decreasing vulnerability in the same manner.

Any increase in the vulnerability of an area to a catastrophic event caused by a hazard for which warning is currently possible places an increased burden on warning systems since the utility of such systems is maximized to its full potential in just such events.

Attributable to shifts in the size and distribution of population, hazard vulnerability is increasing for the hazards of flood, hurricane and tsunamis; it may be decreasing, if even only slightly, for tornadoes.* Consequently, the role warning systems can play in decreasing loss may be seen as escalating in terms of current shifts in population, and in its effect on vulnerability to catastrophe.

Corporate Organization and Size

Corporations are becoming larger. There are increasing numbers of conglomerates with widely dispersed investments in a variety of industrial and commercial endeavors. If such increases in corporate size and diversification mean that there will be proportionately more financial reserves which could be used to cope with hazards (through any mix of adjustments), the trend means that unnecessary losses to hazards could be reduced. Regardless of trends in size, physical dispersion itself makes the possibility of corporate self-insurance more feasible. Large enterprises may be more able to install pre-event adjustments, and more able to withstand the destruction of some segment of their diversified interests or holdings.

Assuming no change in the installation of pre-event adjustments, the trend toward diversification means decreased vulnerability because of increases in the ability of such corporations to sustain loss. Any installation of effective pre-event adjustments would also decrease vulnerability.

These trends could influence the effectiveness of warning systems in two opposing ways. First, as the effectiveness of other adjustments adopted increases, the need for warning may decrease. However, an increasing ability to cope with the hazard (through both pre- and post-event adjustments) could encourage the development of hazardous areas, thereby increasing vulnerability to catastrophic losses, and escalating the need for warning as an adjustment.

Social Guidance

Citizen organizations have recently begun to have impact in areas such as public safety, consumer protection, and environmental issues. Governmental efforts have been made to respond to such groups by, for example, seat belt requirements in automobiles and testing the safety of toys. There does seem to be a trend for increased concern in many

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*See the summary volume in this series for explication of the reasoning behind these projections.

quarters about public safety and consumer protection. It is as yet unclear whether these concerns have carried over into the natural hazards arena as a matter of routine--only a few examples of such cases exist. However, if such a trend is assumed to be present, its effect on warning systems could be dramatic. It could increase the adoption of systems where they do not already exist, or encourage the adoption of system improvements where they do exist.

Public Finance Policy

The detection and forecasting of disaster events remains largely the burden of federally financed agencies. The dissemination of warnings to local public officials is also the responsibility of federally financed agencies, although the dissemination of warnings to the public is the task of local public officials and agents.

A lack of local funds to prepare and maintain the local segments of a warning system (for the reception of warnings and their public dissemination) may in part account for the ineffectiveness of warning systems. If public finance policy at any level of government were to shift to *requiring* new or increased tax appropriations for improved warning systems (equipment, more detailed preparedness, and practice drills) and evacuation plans, an increase may be expected in the effectiveness of the adjustment.

Communication Modes

Changes in systems of communication are directly related to warning systems, since it is through such channels that warnings reach the public. Several communication modes are relevant in terms of present trends.

Adoption of a system such as DIDS to the organizational components of a warning system would increase effectiveness. Current indications are that system costs and privacy reservations on the part of potential users will seriously hamper any attempt to apply the system in private sectors.

A trend seems to exist for some increased local television programming, as required by the FCC.

A slight degree of optimism might be justified in expecting an increase in the use of commercial television for warnings. The adoption of cable television may be seen as a very slow trend when put in national perspective, but if its programming is not limited to canned tapes, it could be very useful for the dissemination of hazard warnings, particularly to sparsely populated areas. There appear to be no serious technical or political constraints involved.

Cable television also seems to offer a significant potential for hazard education. However, such programs usually have few viewers when compared to entertainment programming. Where attempted, evidence shows that public hazard education has not proven effective in upgrading response to hazard warnings (Haas and Trainer, 1973).

A new communication mode is the satellite. There are currently no scientific, technical, or legal constraints to the use of satellites to activate hazard warning sirens at the local level. However, the willingness of community officials to allow local sirens to be activated in such a manner may pose a political constraint. This possibility is especially attractive under conditions where: (1) communities are small and have no around-the-clock personnel authorized to receive and act promptly on warning messages; (2) standard modes of communication are interrupted as a result of the hazard; and (3) the usual modes of communication are overloaded and undependable.

Another constraint seems to be the lack of such warning sirens at the local level. At present there are only a few locations where a siren control is located in the weather office. A specialized Federal revenue-sharing program could conceivably change the situation. There is no evidence, however, that such a move is underway, nor that the use of sirens would increase protective response. The role of sirens in upgrading protective response should be determined.

Others

A variety of the forces and trends which operate in society can have implications on any adjustment to hazards. The preceding trends reviewed have illustrated how such forces could affect warning systems in a variety of ways by either increasing or decreasing system effectiveness, system adoption, or system improvement.

The societal factors reviewed, however, are only a small portion of all possible forces which might affect the adjustment. Others include: (1) an increasing revitalization of the basic value of individualism; (2) community action to decrease vulnerability; and (3) an increasing trend toward multi-family and mobile dwelling units, which is itself the result of larger economic forces.

CHAPTER VI

OPPORTUNITIES FOR RESEARCH

On the basis of the foregoing analyses, areas of research on warning systems which currently promise the greatest reduction in hazard losses are indicated.

In attempting to assess research opportunities, the effort has been to canvass the full range of warning systems, the dynamic factors affecting them, the total benefits and costs to society of current systems, and the likely consequences for society of introducing new information and techniques through research. In no case has it been practicable to identify all of the forces at work or to specify the full social impacts of different warning systems. This fact in itself indicates the desirability of pressing harder for investigation of social response to warnings. The findings presented here represent a judgment based upon sifting of seasoned experience, a necessarily incomplete cost-benefit analysis, and a critical examination of social and physical factors affecting the adoption of warning systems.

Two important policy questions must be considered in estimating current research opportunities for warning systems: (1) how a system should be designed, and (2) how to ensure its adoption and maintenance. Although different in content, each of these questions is directly concerned with the implications research can have for warning system preparedness.

System Design

Research on integrated warning systems is suggested because it is known in abstract generalities what such a system should be, but only with varying degrees of sophistication is it known what is needed in the specific components of the system.

Several factors affecting response, and the implications they have for other parts of the system are evident in Figure II-1, but the most decisive determinants of response in an integrated system are not detailed. Although we have discussed warning dissemination and the processes which precede warning issuance, very little is understood about what affects the dissemination of warnings. It is difficult to make policy-relevant generalizations about how to improve warning content and dissemination procedures. Few recommendations have been made which are applicable to coordination among the varied agencies and the legal and social units in an integrated system.

Two areas of consideration provide the information needed to determine what an integrated warning system should be: response and dissemination. An understanding of both functions indicates the appropriate structure of such warning systems.

1. Warning Response (assessing the warning → response link in an integrated warning system)

A study was conducted in 1969-71 in four Alaska towns to determine the extent to which residents perceived the tsunami hazard, and what kind of public education program would produce the desired level of knowledge about what to do among the residents of an endangered town. None of the education programs used appeared to render any significant change in what residents knew about tsunamis or the warning system, in how reliable they felt the warning system was, or in their expressed intended behavior in response to a tsunami warning.

The evidence, somewhat discouraging, suggests that short-term public education efforts, even intense ones dealing with matters of high salience, *do not have a measurable lasting effect* (Haas and Trainer, 1973; Baker, 1971). Research on the effectiveness of education programs for seat belt wearing and cigarette smoking reveals similar results. Our conclusion is that community public education programs, per se, have little direct benefit for natural hazard warning response, because of infrequency of hazard strikes in the same area.

Evidence suggests that a significant portion of a populace fails to evacuate regardless of warnings received. Research in the airline industry has shown that in situations where planes have to be quickly evacuated (while on the ground), passengers must be literally thrown out of the airplane. There are many more such examples. Even with elaborate means for evacuation and detailed plans of preparedness which have not been based on detailed knowledge of what affects response, the effectiveness of warnings is very uncertain. Only with greater understanding of the likely responses of individuals and groups under disaster threat would it be possible to make those precise refinements in warning systems which would result in greater benefits from protective action and warning preparedness. This is a crucial area for study. The basic question is how to align and structure warning dissemination to allow adaptive action to be a real alternative in times of impending disaster. As Meta Systems has stated in its report on Tropical Storm Agnes, "there is an important difference between awareness of what may happen and the summoning of energy necessary to do something about it" (1972, p. 101).

In situations where warning systems can function to avert catastrophic loss of life and movable property, an integrated sociological and social-psychological all-hazard research project should be systematically conducted to refine present knowledge and expand upon it. The study should provide a base to assure that public response to warnings of unique events could be planned within an integrated warning system.

The study should be designed to determine how hazard warnings can be structured, worded, and delivered to a public so that appropriate and expedient response to hazard warnings can be achieved. Ideally, the findings and conclusions of the study would apply to the dynamics of all integrated warning systems. To that end, a series of different warning-response events should be studied in a variety of hazards. This cross-hazard approach would allow control for hazard type in the analysis, thereby aiding the determination of other factors' effect on response to warnings. The cross-hazard approach might also permit the extension of findings to other warning-related hazards, and multiply the applied relevance of the findings.

An examination of warning-response across different hazards would require a funding level of eight person years* per year for a period of approximately eight years. This expenditure and time period are required if the research effort is to be of sufficient scope and magnitude to accomplish fully its goals. A minimum of 40 actual events should be studied in order to represent adequately a sampling of different dramatic warning event hazards, and to ensure a minimum level of

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*A person year is the amount needed to support one research worker, including staff and travel, for one year; currently $60,000.

acceptability for the generalization of the findings for policy recommendations.

Such an integrated cross-hazard program of response research would be more fruitful and less costly in the long run than individual hazard-specific warning response studies. It would allow for the standardization of instruments of measurement, permit a variety of factors to be controlled for in each event, and make the results of each separate event comparable to results for other events studied.

This is not to say that information which has been, or may be gathered as a result of individual studies is not significant. However, a broader project would produce the required findings at a significant reduction in total cost and in a fraction of the time by allowing comparability to exist between each event studied. Done as individual unrelated projects, far more than the 40 events would have to be assessed to allow cross-event comparison to be made.

The study should include a comprehensive sample of events of all hazard types in which random samples of the public exposed to warnings in each event are assessed for the following characteristics in the face of threat: (1) exposure to the messages; (2) message type (for example, content, specificity, style of presentation and source); (3) belief and credibility; (4) understanding and misinterpretation; (5) knowledge of appropriate action; and (6) behavior. The study should review these factors as they are associated with warning response to different kinds of threat situations, in different circumstances, in different kinds of communities, and on different specified groups of people (for example, the aged, the poor, the experienced, and the fearful).

The respondent factors which might be reviewed are illustrated in Figure II-2. The respondent factors and community factors include the various components of community evaluation-dissemination in an integrated warning system. For example, the role which sirens can play in alerting a public should be determined. If their use assists response, that fact is important to know in structuring integrated warning system preparedness. The study should seek to explain how people react to warnings of different kinds and degrees of natural hazard threat. This information could be actively incorporated into integrated warning systems to maximize the benefits.

The study should not approach warning response in vague terms or glaring generalities. Rather, the response should be described in measurable dimensions so that it might be predicted quantitatively from the explanatory factors included in the analysis (examples of such analyses are Drabek, 1969; Drabek and Stephenson, 1971; Mileti, 1974). The goal would be to make inferences about response which could be used to improve the legal and institutional structure of integrated warning systems and preparedness. As Meta Systems (1972, p. 103) stated:

> The question is how to align the information-dissemination systems so that the levels of warning are distinct from each other and so that it becomes possible to discriminate the serious kind of warning (which calls for action) from that which does not, all the while having reasonable assurance that people will respond appropriately to a timely and urgent warning of real disaster.

Public response is the ultimate reason for having any warning system. The lack of serious attention given to it in warning system preparedness, and to research to assist in planning those systems is puzzling.

2. Warning Content, Style, and Psychological States

Although the real-world research proposed would yield information on how differences in warning affect actual behavior, a need also exists to determine how differences in the warning source, the content, and the mode of communication would affect psychological states in those who might respond. A series of social-psychological laboratory experiments are called for in which factors such as the number of warnings issued, specificity in warning content, and the wording of messages are related to psychological factors such as warning belief, definitions of danger, and fear. This would resemble the work reported in McGuire (1969, p. 205) on fear, anxiety, and attitude change and fear-appeal research.

Experiments should investigate both attitudinal and behavioral measures of the effect of simulated warnings. The findings might be made generalizable to the real world by ensuing field observations. However, the wisdom of carrying out such a rigorous field experiment is questionable; the ultimate variable manipulated may be death. Nevertheless, policy findings could be generated from the laboratory experiments. If implemented in the real world, their effectiveness could be assessed in part by comparing disaster communities in which they had been applied to those in which they were not.

The exploratory laboratory work could be accomplished easily within one year if it were supported at a level of two person years. Were results promising, the findings should be directly incorporated into warning preparedness programs for all who are concerned with dispensing warnings to the public.

3. Warning Dissemination (assessing the hazard → warning dissemination link)

Certain stipulations apply to the effectiveness of any message from a warning system: (1) if the message is received at the local level without alteration, it must be received promptly and it must contain clear, concise information which can be easily and quickly understood by the local individual, whether official or other resident (Anderson, 1970); (2) if the local official or other recipient successfully disseminates the information to all relevant local persons, the information must be received promptly and the message or signal must contain the information necessary for residents to make rapid, rational decisions about appropriate actions; and (3) if the local resident interprets the message or signal correctly, he must know what action should be taken and he must be motivated to take the appropriate action in time. If the local resident's action is to be of an appropriate nature, it should prevent loss of life and injury, it must minimize property damage, and there must be a "safe area" that can be reached in time (Haas and Trainer, 1973, p. 9).

When one or more of those conditions is absent, the intended objective of the warning system will not be achieved. As demonstrated, there are many links in the effective warning chain; each link is of the same importance. This factor is especially problematic since numerous groups and government agencies divide the responsibility of many of the processes in a warning system. The current division of responsibilities among these groups is a source of difficulty in the evaluation-dissemination sector of warning systems.

Little is known about how warnings come to be issued to the general public. We know that factors such as the past experience of warning officials, perceived negative public reactions on the part of warning officials, and routine communication patterns between warning-related organizations help explain why and how warnings are disseminated.

Nevertheless, knowledge is too sparse to make policy recommendations for altering the structure of warning systems and preparedness to guarantee that adequate warning will be issued when needed.

Integrated cross-hazard research on warning dissemination is ranked high among warning system research needs. Once again, a cross-hazard approach is seen as the most expeditious and least costly means of attaining the required knowledge. The reasons are the same as those reviewed when we pointed to cross-hazard research on warning response: comparability between events would be maximized, and the possibility of controlling for hazard factors would give more reliability and usefulness to research findings.

A research project designed to assess warning dissemination would likely run for about five years at an annual funding level of ten person years. This time period and funding level is required because the study should be one in which a variety of hazard events and types are assessed, but not in the traditional post-audit descriptive fashion. A quantified determination should be made of the links in the processes which affect warning dissemination across an adequate sample of warning events.

The sample of events should be large enough for analysis to be made, but with controls for varied factors such as community and hazard type. A minimum of 35 events in different communities would be necessary to result in generalizable policy recommendations on dissemination in integrated warning systems.

Such research should address the manner in which warnings might best be disseminated, the means for overcoming those constraints (economic, legal, political, and social) which function to retard warning issuance, and what changes in structure in responsible agencies would maximize good warning dissemination. The study should be a quantified assessment of all aspects of the processes which precede warning dissemination--detection, measurement, collation, interpretation, the decision to warn, and formation of message content--how those processes influence what is actually disseminated, and the feedback relationship from response to the dissemination process (see Figure II-1).

Cross-event comparisons of quantified factors, in the fashion in which Anderson (1969) has made such comparisons, probably would produce generalizable results.

Adoption and Maintenance

Warning systems cut across a variety of legal boundaries, Federal detection agencies, regional weather services, and local officials and media broadcasting agents. Once a particular mix of relationships between these units has been found desirable for an integrated system, those measures must be adopted at local levels if the nation is to benefit. Two constraints may deter adoption of such systems: (1) the requisite appropriation of funds may be difficult to obtain at the local level for an event which may not occur often; and (2) other community problems which are immediate and visible can easily supersede preparations for the rare event. Even when adopted, the maintenance of systems at a functional level often falls into decay. Knowledge is seriously deficient on what can affect adoption, and what assures ensuing system maintenance (preparedness) at the community level.

It may be that the tornado warning system in an area repeatedly struck by tornadoes is more efficient in structure and efficacy than a flash flood warning system which is rarely used. If this is the case, one might expect a crucial question for system adoption and maintenance to be the level of community hazard awareness. Such awareness may be influenced by other factors as well as by the repetition of the hazard agent.

System adoption may be the result of a combination of factors, among which might be hazard repetition, community officials' awareness, legislated requirements at the local level, and the degree to which systems can be "piggy-backed" onto existing community structures. The maintenance of systems may well be affected by these very same factors.

In an attempt to generate knowledge in the least costly and most efficient manner, research into the adoption and maintenance of warning systems would best be integrated into one endeavor. Both components of the effort are directly concerned with preparedness, and would generate results across the dramatic event hazards previously specified. This is not to say that hazard-specific research would not also produce meaningful results, nor that research aimed at adoption or preparedness for individual existing systems would not be beneficial. These are viable alternatives to the research design proposed. They are, however, more likely to increase cost and time. Studies of individual hazards which are separate from each other might also be less comparable and inhibit the potential benefit which could be realized in cross-hazard research. The latter offers the bonus of approximating an experimental design.

No significant benefit will be attained from research on any component of warning systems unless what is currently known and what is discovered is put to use in specific communities for preparing for specific events. Few communities have established detailed warning systems; those which do, often fail to maintain them. We have pointed to research to define the parameters and components of what we consider to be the most feasible and promising warning system. We here call for research which would enable the installation and maintenance of such systems.

Such a study should produce relevant results within four to five years if supported by an annual expenditure of 20 person years. This level of support is needed to: (1) identify what factors account for the systems which are presently adopted (how closely they resemble an integrated system), and what factors account for the intensity with which those systems are maintained; and (2) introduce controlled information into different groups of communities in an effort to determine how to upgrade adoption levels and preparedness. The second effort should be based upon information gained in the first part of the study.

In order to accomplish both objectives the effort would have to examine a minimum number of approximately 50 communities so that account could be taken of factors such as hazard type, type of community, and warning system existence and type. Fewer than the specified number of communities would under-represent several vital and relevant elements.

The unit of analysis for this study would be warning systems as their links *stand dormant* in the ongoing routine of community life. It would not center on post-audits of warning systems. The study would examine community experience, size, type, organization, political composition, and hazard awareness. One finding of the study might well be that the adoption and maintenance of warning systems at the local level can be expected to reach maximum effective levels only when required by appropriate legal directives. Whatever the results, this study should contribute insights on how to upgrade the adjustment's adoption and maintenance.

No past research effort has been located which attempted to make a comparison of dormant warning system linkages in order to determine what factors explain adoption and preparedness. Such a study, or even the more costly alternative of a series of studies, is central to reaping maximum benefits from any future research on natural hazard warning systems, both in terms of average annual benefits or of catastrophe avoidance.

Table VI-1 evaluates the research opportunities on integrated warning systems; Table VI-2 indicates funding levels.

Issues for Other Hazards

Warning-related issues which do not apply directly to dramatic event warning systems--whether related to prediction, warning dissemination, or response--as they apply to either a specific hazard or to other adjustments, are here discussed in greater detail and in reference to specific research recommendations in individual hazard or sector monographs in this series.

1. Warning Applicability

For the hazard of coastal erosion, there is no concrete information about the effectiveness of erosion warnings in reducing the costs of the hazard. There are wide disparities in responses to warning in different coastal communities. Additional research is needed to determine whether the existing service merits expansion or elaboration. This should include identifying the portion of a target population which receives the warning, and analysis of its subsequent responses. Such an investigation should also assess the feasibility of improving short-term warnings by analyzing a broad range of erosion factors, rather than by relying on damage projections based on expected high water levels.

For the hazards of snow and frost, there is no doubt that warnings mitigate net loss (warnings of heavy snow allow for the mobilization of urban snow removal teams, and warnings of frost allow citrus growers to light smudge pots in their groves). It is apparent, however, that those who benefit most from warnings for the two hazards get them with sufficient efficiency *relative* to current forecasting abilities.

Better forecasting could possibly reduce losses and even upgrade the potential rewards from dissemination research. If improvements in snow prediction were found to be practicable, additional research on the dissemination of a snowfall prediction would be in order. Such research should be small in magnitude and focus on distribution and

TABLE VI-1 EVALUATION OF PROPOSED RESEARCH

Research Opportunity	Benefit-Cost Analysis (Net Pecuniary Benefits)		Reduction of Fatalities		Reduction of Social Disruption		Protection/ Enhancement of Natural Environment	Contribution to Equity of Income Distribution	Expected Success of Research	Political Feasibility of Adoption
Hazard Type	Average	Catastrophe	Average	Catastrophe	Average	Catastrophe	Average	Average		
Research										
Warning Response	Medium-Low	Low	Medium	High	Medium	Medium-Low	Low-None	Medium	Medium	High
Warning and Psychological States	Medium-Low	Low	Medium	High	Medium	Medium-Low	Low-None	Medium	Medium	High
Warning Dissemination	Medium-Low	Low	Medium	High	Medium	Medium-Low	Low-None	Medium	Medium	High
System Design, Adoption and Maintenance	Medium-Low	Low	Medium	High	Medium	Medium-Low	Low-None	Medium	Medium	High

TABLE VI-2

FUNDING LEVELS FOR RESEARCH OPPORTUNITIES

Research Opportunity	Current Annual Funding Level[1]	Suggested Additional Research In Person Years[2]	Time Horizon for Research (Years)
SYSTEM DESIGN			
1. Warning Response	[3]	65	8
2. Warning and Psychological States	0	2	1
3. Warning Dissemination	[3]	50	5
ADOPTION AND MAINTENANCE	1	100	5

[1] 0 = no expenditure or less than $10,000
1 = $10,000 - $100,000

[2] Funds needed to support one research worker, including staff and travel, for one year; currently $60,000.

[3] Funding only for post-audit Natural Disaster Survey Reports series by NOAA.

content of warning messages from a forecasting organization to decision-makers at all levels. Mass abandonment of vehicles, overloads at road conditions report switchboards, and subscriptions to private forecasting services now suggest that improved dissemination of snow warnings might have a beneficial effect and could reduce disruption.

Research on warning dissemination and response for the lightning hazard does not promise a reduction in losses.

2. Warning Feasibility

Techniques for earthquake prediction and forecast are developing, and some sources are optimistic about feasibility. A series of issues concerning what might be done with the forecast must be addressed.

It is our understanding that research on earthquake prediction and forecast is presently funded at approximately $6 million per year. This rate seems reasonable considering the magnitude of the geophysical problem. However, since seismologists seriously expect that forecasts of date and place of major earthquakes will be issued, officials--public administrators, security officers, broadcasters, and earthquake forecasters themselves--should be fully aware of the possible responses to such forecasts: the response of the general public, of local business, of regional business, of local health and safety groups, and of national health and safety groups. The political, social, legal, and economic consequences of a forecast must be considered, as must responsibility and mode for issuing warnings.

This is a subject for a complete program of social and behavioral research on a warning system which should be carried on simultaneously with the seismological research program on prediction and forecast, but organized and funded independently.

On a smaller scale, if drought forecasts were to be produced accurately, assessment should be made of how that information would be best used by involved agencies.

3. Warning Interactions

Because of the physical characteristics of some natural hazards, warnings of their possible onset can take on profiles quite different from those of dramatic event warning systems. Warnings may be only indications that hazards may strike at some unspecified time in the future. For example, hazard-risk delineation in a mountain community could identify areas subject to hazards such as avalanche or landslide. The warning inherent in the detection of hazard risk is a component of implementating other adjustments such as effective land use or building codes.

Anticipated Benefits

1. Benefits

Any future research into dramatic event warning systems must take two issues into account: (1) trends in potential for catastrophe; and (2) average annual hazard losses.

Catastrophe potential is on the rise for all eight natural hazards for which dramatic event warning systems are feasible. Even though data indicate that the average number of annual deaths from hurricanes is declining, data also indicate that deaths from hurricane-induced major catastrophes are increasing. In addition, the potential for hurricane-induced catastrophe is rising due to increases in population and concentration in hurricane-prone areas of the country. Warning systems could reduce losses effectively in catastrophic events.

The potential benefits from research into warning systems must also be assessed in terms of *average economic losses* for specific hazards. Although the hazard-specific estimates appear in the individual hazard monographs in this series, it will be helpful here to detail our reasoning on a few hazards.

The occurrence of hazards like volcano and tsunami is so rare that viewing yearly averages is meaningless. The only real topic for assessment is the isolated catastrophic event. It could be of a magnitude of 500 lives in one event alone.

The loss of life to tornadoes in yearly averages is relatively small given the frequency of the event. For the period 1960-1970, there was an average of 101 deaths each year attributable to tornadoes, and in only one of those ten years was the death toll greater than 140 deaths. For the period 1960-1970, there were only 0.137 deaths per observed tornado. In yearly *averages*, the "loss of life" criterion for tornadoes is a weak rationalization for additional monies being spent on warning research, although recently over 370 persons lost their lives from tornadoes in one day of catastrophes.

The same conclusion may be reached for tornadoes in reference to *average* loss of property. In most tornado disasters, the majority of losses is from complete or partial destruction of buildings. We cannot see how an improved warning system would reduce any building losses. Very little can be done in a few minutes or hours to preserve a roof. An improved or "perfect" warning system would have little effect in reducing the bulk of the average damages due to tornadoes. In a tornado catastrophe, warning systems could reduce the total number of tornado deaths and injuries substantially, although it would probably do little to reduce property loss.

For the flood hazard, however, a substantial reduction in average annual property loss could be realized (our bottom estimate is 5% of $2 billion, or $100 million). This is based on the fact that for the slow-impact flood hazard, upgraded warnings could facilitate the removal of movable property from the hazard area, or to high and dry parts of buildings within the area.

Past research indicates a 5-20% reduction in loss from warning-dependent non-structural emergency actions (White, 1964). Effectiveness depends upon flood variables, especially stage and onset, and upon the nature of the flood warning system and degree of human responsiveness.

An effective warning with at least one hour lead time and an effective response to warning may enable non-structural emergency action to affect flood damages in the manner indicated by White (1964, p. 66), as shown in Figure VI-1.

Although it has been suggested that about 40 hours lead time is required to attain maximum effectiveness in avoiding damage (see Figure VI-2), experience suggests that for small communities on tributary streams lead time could be much less, perhaps 12 hours, if the community is well-informed (White, 1964, p. 66).

The potential rewards to be gained from warning system research for floods is a 1:20 ratio of research cost to property loss aversion, when total suggested research expenditures are considered in light of the $2 billion annual property losses associated with floods. This suggests that the research opportunities which now exist are economically practical. However, even greater rewards may be expected because the research is also applicable to the seven other dramatic event hazards in terms of property loss, deaths, injuries, catastrophic events, and annual losses.

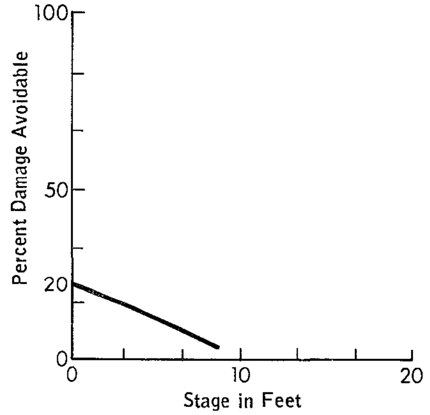

FIGURE VI–1

PERCENT DAMAGE AVOIDED BY NON–STRUCTURAL EMERGENCY ACTIONS UP TO TEN–FOOT STAGE

(White, 1964)

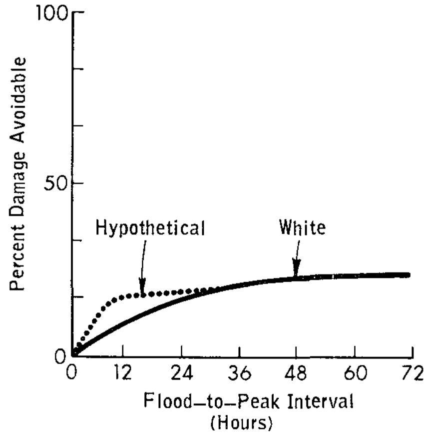

FIGURE VI–2

PERCENT DAMAGE AVOIDED BY NON–STRUCTURAL EMERGENCY ACTIONS FOR VARIOUS WARNING LEAD TIMES

(White, 1964)

2. Utilization of Findings

Those involved in any research on practical and applied issues must realize their obligation to deal with the application of relevant results. Eventual utilization should be as important an objective to any such research effort as ascertaining immediate research goals. Consulting, teaching, and carrying the information to users insure utilization.

Methods of earthquake-resistant design are now in common use in the state of California for dams and other hydraulic structures, and originated out of recommendations from earthquake design research and endeavors to make those recommendations known. Similar results could be expected in other lines of research if researchers concern themselves as centrally with implementation as did the earthquake design engineers.

We might expect implementation to be the result of "the residual effect." In a research effort mentioned earlier in this report on the response of three Alaskan communities to tsunami warning (Haas, 1971), the researchers reported that official awareness of the hazard increased apparently as a result of fieldwork. Warning systems, at least during the time period for which information is available, were upgraded because of the raised awareness the fieldwork brought to the officials involved in the warning systems. Although reliance upon this benefit of research should be guarded, it too must be considered in the net applied benefit of any research endeavor.

A lack of communication between the scientific community, user agencies, and the public hampers the amount of information given to disaster management and administration. It is hoped that the examples stated here illustrate how this serious problem might be dealt with.

In summary, there is indication that hazard losses can be reduced by utilization of research findings on (1) the social and psychological factors which affect warning response; (2) the links among the groups and agencies which evaluate threat information and disseminate public warnings; (3) warning content and modes of communication; and (4) means to secure the adoption and maintenance of integrated warning systems in adequate preparedness programs.

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