

COMMUNICATION OF EMERGENCY PUBLIC WARNINGS

**A Social Science Perspective and
State-of-the-Art Assessment**

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ABBREVIATIONS, ACRONYMS AND INITIALISMS

CAWP	Colorado Avalanche Warning Program
CDWS	Civil Defense Warning System
DOT	U.S. Department of Transportation
EBS	Emergency Broadcast System
EOC	emergency operations center
EPA	U.S. Environmental Protection Agency
EPZ	emergency planning zone
FEMA	Federal Emergency Management Agency
FBI	Federal Bureau of Investigation
NAWAS	National Warning System
NEHRP	National Earthquake Hazards Reduction Program
NEPEC	National Earthquake Evaluation Council
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Air Defense Command
NRC	Nuclear Regulatory Commission
NRT	National Response Team
NSSFC	National Severe Storms Forecast Center
NWS	National Weather Service
NWWS	NOAA weather wire service
OES	Office of Emergency Services
PA	public address
RCRA	Resource Conservation and Recovery Act
SARA	Superfund Amendments and Reauthorization Act of 1986
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WSFO	Weather Service forecast offices
WSO	Weather Service Offices

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ABSTRACT

More than 200 studies of warning systems and warning response were reviewed for this social science perspective and state-of-the-art assessment of communication of emergency public warnings. The major findings are as follows.

First, variations in the nature and content of warnings have a large impact on whether or not the public heeds the warning. Relevant factors include the warning source; warning channel; the consistency, credibility, accuracy, and understandability of the message; and the warning frequency.

Second, characteristics of the population receiving the warning affect warning response. These include social characteristics such as gender, ethnicity and age, social setting characteristics such as stage of life or family context, psychological characteristics such as fatalism or risk perception, and knowledge characteristics such as experience or training.

Third, many current myths about public response to emergency warning are at odds with knowledge derived from field investigations. Some of these myths include the "keep it simple" notion, the "cry wolf" syndrome, public panic and hysteria, and those concerning public willingness to respond to warnings.

Finally, different methods of warning the public are not equally effective at providing an alert and notification in different physical and social settings. Most systems can provide a warning given three or more hours of available warning time. Special systems such as tone-alert radios are needed to provide rapid warning.

1. INTRODUCTION

1.1 PURPOSE

The major tools available for responding to the risks and effects of hazards and disasters are land-use controls, insurance, engineered protection works and construction standards, disaster response plans, and emergency warning systems.

Warning systems bear an interesting relationship to other hazard management tools. They are last lines of defense after, for example, engineered solutions are applied to reduce the probability of an event below some acceptable level. Additionally, warning systems for low-probability events often do not make cost-benefit sense. Warning systems are economically rational only when a risk becomes an actual event and when having inadequate or no warning systems is politically and socially unacceptable.

Warning the public of an impending risk is an everyday occurrence in the United States. We have estimated that public emergency warnings are issued, on the average, at least once a day and perhaps even more frequently. The actual number of people who are warned varies across events. For most events, only a few dozen persons need to be warned. However, many events occur that call for warning a population of substantial size. Furthermore, a warning event is often locally unique, although in some communities warnings are more commonplace (e.g., flood warnings along the Mississippi or tornado warnings in Kansas). Warning systems can also be used to communicate information about safety as well as risk; this aspect of warning systems is important because in most warning events more people who can hear the warning are safe than are at risk.

One general purpose of this work is to explore why, from a social science viewpoint, warnings are sometimes effective and sometimes not. Disaster sociologists began to address this issue some three decades ago. Early efforts (Lachman, Tatsuoka, and Bonk 1961; Mack and Baker 1961; Withey 1962; Moore et al. 1963; Drabek 1969) and subsequent studies revealed that discoverable patterns do exist in public warning response. The initial research efforts were followed by several attempts to organize research findings (Withey 1962; Williams 1964; McLuckie 1970, 1973; Mileti 1975). Both original research and attempts to summarize findings have continued (Perry 1985; Drabek 1986); in the last decade, the number of actual studies of public response to disaster warnings has almost doubled. There are now about 200 publications on response to public warnings.

Social science research on emergency warning systems has not been limited to public response studies. Efforts have also been undertaken to understand warning systems from an organizational viewpoint. For example, research has sought to address the structure and processes of organizations involved in detecting the presence of an impending disaster, the evaluation of risk data, and the analysis of variation in the timeliness and content of actual warnings issued to the public. The first systematic attempt to study these organizational aspects of warning systems was conducted by Anderson (1969), and additional studies along this research vein have been conducted in the last two decades (Dynes et al. 1979; Sorensen and Gersmehl 1980; Saarinen and Sells 1985). Several attempts have also been made to systematize these findings (Mileti, Drabek, and Haas 1975; Mileti, Sorensen, and Bogard 1985). However, there are only a few actual analytical case studies on this topic; there are also some three to four dozen anecdotal case histories in print.

Research has also been conducted on warning system technologies, including work on improved technology such as sirens with more audible signals, on increased systems reliability such as more dependable remote activation equipment, and on new technologies such as remote-activated FM radio receivers. A detailed review of such research is beyond the scope of this report, although the report does incorporate current knowledge on technology into the analysis (Tanzos et al. 1983; Towers et al. 1982).

Although several bodies of literature are related to studies of warning and response in emergencies, this study is limited to research on collective stress warning situations involving whole communities or large portions of communities. Considerable attention has already been given to human behavior in building fires (Keating et al. 1983). Human factors research also includes the investigation of response to different type of alarms in a work setting (Hakkinen and Williges 1984); and there is a growing literature in industrial safety about the effectiveness of hazard warnings on placards (Wolgalter 1987). Similarly, in the area of consumer safety, investigations have been conducted on warnings on product labels (Lehto and Miller 1986).

Much is obviously known, from organizational and public response viewpoints, about why warning systems are sometimes successful and sometimes unsuccessful. Despite this knowledge and in spite of prior attempts to pull research findings together in propositional inventories and models, several questions about warning systems remain unanswered.

First, although a rich set of data on human response to disaster warnings exists, a synthesizing theory has never been imposed on these empirical findings. Consequently, we lack a consistent, comprehensive explanation for warning response. In this work, it is our purpose to attempt to achieve this objective—for both public response and organizational aspects of warning systems.

Second, we seek to draw conclusions based on the research record regarding how to build a "good" warning system; that is, how does one design a warning system that takes advantage of existing social science knowledge and current technology to maximize the probability that the system will be effective when implemented.

We also examine existing warnings systems in the United States for over a dozen different hazardous event types. In addition, we evaluate multihazard or overlapping warning systems—that is, the different warning systems needed for each hazard type and the extent of any overlap. Finally, we take stock of current research needs.

1.2 CURRENT WARNING SYSTEMS IN THE UNITED STATES

The nation has constructed warning systems for a wide range of events that can impose a quick-onset threat to the public. Geological events of this sort include earthquakes, volcanic eruptions, tsunamis, and landslides. Climatological hazards that can quickly strike a population include hurricanes, tornadoes, floods, and avalanches. Technology has also imposed emergency situations requiring public warnings. Some of the most obvious are nuclear power plant accidents, hazardous material production accidents at fixed sites, hazardous material transportation accidents, and dam failures. In addition to hazards from the natural and technical worlds, there are two particularly serious social hazards—nuclear attack and terrorist activities. These geological, climatological, technological, and national security events have several important common elements: (1)they represent low-probability risk events that can materialize; (2)they can pose the threat of widespread disaster for a human population when they do occur; (3)their potential impact can be detected; and (4)a public protective response before impact can

enhance safety, reduce losses, and save lives. Consequently, public warning systems can be of utility for each of these classes of events, and, in varying degrees, warning systems are currently in place for each of them.

This section reviews the warning systems in place in the nation for each of 14 events. Our emphasis is at the national level for two reasons. First, most detection and forecast efforts are national. Second, local efforts in warning systems are simply too numerous to fit the purpose of this work, although levels below the national one are referenced when a particular warning system being reviewed contains clearly critical subnational detection and forecast elements. As the reader will soon be able to conclude, existing warning systems range from the very elaborate, in the case of nuclear power plant accidents and hurricanes, to those which are relatively underdeveloped.

1.2.1 Earthquakes

The Earthquake Hazards Reduction Act of 1977 established the National Earthquake Hazards Reduction Program (NEHRP). The overall goals of this program are to reduce loss of life and property from earthquakes, and to mitigate the severe socioeconomic disruption that could be induced by a catastrophic earthquake. A range of federal agencies participate in this program, and each works toward the accomplishment of one or a mix of principal NEHRP activities. These include hazard delineation and assessment, seismic design and engineering research, preparedness planning, and earthquake hazard public awareness. Basic research is funded by the National Science Foundation; however, it is the U.S. Geological Survey (USGS) that holds program and operational responsibility to conduct research that could lead to earthquake predictions and warnings.

The scale for ranking general earthquake hazards information and specific predictions and warnings does not provide a clear distinction as to what constitutes an earthquake warning and what does not. Currently, predictions are classified as long-term, intermediate-term, and short-term. A long-term classification can rest on earthquake potential studies, while a short-term classification would most likely result from actual prediction research. All three classifications provide information about earthquake risk that could suggest appropriate responses to members of the public, ranging from the purchase of earthquake insurance in the case of a long-term prediction to evacuation after a short-term prediction. It is less likely that a scientifically credible short-term prediction would occur in an area not already classified as having long-term earthquake potential: the long-term classification is almost certainly needed to direct the intensified scientific studies requisite for a short-term prediction. Our attention is focused solely on short-term prediction activities that could give rise to a public warning.

Earthquake prediction research within USGS includes the collection of observational data and the development of the instrumentation, methodologies, and understanding necessary to predict damaging earthquakes. Prediction-warnings of this sort would need to be of a time interval that is long enough to allow for public response to the warning and precise enough to avoid unnecessary socioeconomic impacts.

Under the Disaster Relief Act of 1974, USGS has the responsibility to notify appropriate federal, state, and local authorities of earthquake hazards and to provide information as necessary to ensure that timely and effective warning of potential disasters is provided. The director of USGS is charged by the Earthquake Hazards Reduction Act of 1977 (as amended in 1980) with authority to issue an earthquake advisory or prediction as deemed necessary. Such an advisory would be issued after the scientific evidence for a prediction is assembled and presented to the

National Earthquake Evaluation Council (NEPEC). Should NEPEC judge that there is scientific merit to a prediction, it would so inform the director of the USGS, who could then issue a prediction to federal, state, and local authorities. Public warnings could then be issued by state offices of emergency services, or by county and city authorities.

The state of California has the most detailed prediction-warning planning. In California, the California Earthquake Prediction Evaluation Council would convene to advise the governor or the governor's Office of Emergency Services (OES) on the scientific merit of prediction. It is also planned that USGS, OES, and the California Division of Mines and Geology could coordinate the issuance of a prediction statement. At present, OES would inform local counties and cities of the prediction, and OES might or might not participate with them in the preparation and dissemination of emergency public warning messages.

1.2.2 Volcanoes

USGS, which conducts basic volcanological research and monitors volcanoes, has the responsibility of assessing the hazards and predicting eruptions of volcanoes. Under the Disaster Relief Act of 1974, USGS is charged with providing technical assistance to state and local government for disaster warnings, including warnings regarding volcanic eruptions.

USGS operates two volcano observation stations for monitoring volcanic activities and conducting research. The Hawaiian volcano observatory has operated since 1922 (and under the direction of USGS since 1956) to study and predict eruptions at Kilauea and Mauna Loa volcanoes. The Cascades Volcano Observatory in Vancouver, Washington, was established in 1981 to study and monitor Cascade volcanoes.

Most warning systems must be tailored to a single volcano or cluster of volcanoes because each volcano is unique. The techniques of volcano monitoring are relatively standard. The basic instruments of hazard monitoring are seismographs, which indicate lava movement; tiltmeters, which indicate inflation and deflation; electronic distance-measuring instruments, which measure lateral displacement; geotimeters, which measure horizontal displacement; surveying equipment, which measures displacement; theodolites, which measure vertical angle changes; and gas sniffers, which analyze gas composition. All provide data useful to short- and long-term predictions and warnings. Volcanoes are also monitored by satellite and air imagery and visual monitoring. The latter is often the only way to detect an actual eruption even in our highly technical age. Radar can be used to track ashfall after an eruption.

The information provided by USGS to state and local officials is usually in a form that is not easily translated into a public warning. While, in some cases, monitoring can provide information on whether an eruption will occur, in others it can predict only probability. Moreover, the precise time, kind, and magnitude of an eruption cannot be easily predicted. USGS can delineate probable impact zones for various hazards on the basis of historical studies, but these are by no means exact boundaries. These predictions are limited by the general problems of extrapolation from historical record; an eruption could exceed the magnitude of previous ones, take a different course, or otherwise vary from recorded behavior.

Different volcanic hazards may require diverse warnings. Volcanic hazards include ash, floods and mud flows (lahars), avalanches, landslides, pyroclastic flows, lateral blast, and lava flows. Secondary hazards include fire and dam failures. Each poses somewhat unique threats to human safety, and some have secondary impacts on environmental systems such as water supply or power systems.

USGS works with media and public officials to provide them with available information on volcanic hazards but does not assume responsibility for disseminating that information to the public. This process varies from site to site and depends on the assumed roles of state and local government and other organizations. At Kilauea, public warning processes are tightly controlled by the county government. At Mount St. Helens, the authority was divided among multiple agencies with no central control. Other potentially hazardous volcanoes, such as Mount Baker or Mono Lake, also have different public information and warning arrangements. One deficiency of volcanic hazard warning systems is the lack of attention given to getting warnings to the public. The failure to warn residents of eastern Washington of ashfall from the massive May 18, 1980, eruption at Mount St. Helens is an example of the effects of an inadequate volcano warning plan.

1.2.3 Tsunamis

Tsunamis are large sea waves generated by seismically induced underseas displacement, avalanches, or volcanic activity. There are two types of tsunamis—distant tsunamis, which travel across the ocean from one coast to another and local tsunamis, which are generated just offshore and travel short distances. The two types pose very different warning problems. Tsunamis occur mainly in the Pacific Ocean; consequently, California, Oregon, Washington, Alaska, and Hawaii are vulnerable to both types of events. Tsunamis are extremely rare events in the Caribbean and on the Atlantic coast. As a result, tsunami warning systems have been developed only in the Pacific.

Distant tsunamis are detected through the Seismic Sea Wave Warning System, developed in 1948 and located in Oahu, Hawaii (Pararas-Carayannis 1986). The May 1960 Chilean tsunami convinced many countries to join the Pacific tsunami warning system. In 1965, the United Nations Educational, Scientific, and Cultural Organization joined the United States to expand the Tsunami Warning Center in Honolulu. Twenty-three nations are now members of the International Tsunami Warning System. The warning system uses a Pacific-wide network of seismograph and tide-monitoring stations. The seismograph stations detect and measure the size and location of undersea earthquakes capable of generating a tsunami. On that basis, the Tsunamis Warning Center in Honolulu issues a tsunami watch, which alerts coastal areas to the possibility of a tsunami and its estimated arrival time, should one have been generated. Next, tide stations nearest the epicenter are contacted to watch for the signs of a tsunami. While such waves cannot be readily seen in open waters, they can be technologically detected as distinctive abnormalities. If these abnormalities are detected, arrival times are calculated for various locations. The observatory then contacts a single warning point in each country in the Pacific region.

The public dissemination of a warning varies with location. In Hawaii, distant-tsunami warnings are issued by state and county civil defense groups, using an elaborate siren system. Maps in telephone directories outline potential run-up zones. A distant tsunami allows police and emergency officials time to get warnings to those who might be affected.

Two local-tsunami warning systems are also in operation in Alaska and Hawaii. In Alaska, the Palmer Observatory collects data from a network of seismographs. When a major earthquake occurs along the coast of Alaska, an immediate warning is issued to civil defense or emergency offices in a 200-mile radius around the epicenter. If wave abnormalities are then detected, the warning is issued for the entire coast of Alaska. The Hawaiian local tsunami system uses seismographs as well as pressure-sensing instruments on the ocean floor and tide stations to

detect earthquakes and tsunamis. When an earthquake of a size and location capable of producing a tsunami is detected, a warning is immediately issued through the Office of Civil Defense. Tide monitoring will confirm whether or not a tsunami has actually occurred, and the warning is quickly adjusted or cancelled.

Local-tsunami warning systems must quickly alert coastal residents to danger. In Hawaii, sirens are the primary mechanism for warning. In more remote locations where fatalities have occurred, signs have been erected instructing people to get above markers showing safe locations when "natural" warnings are experienced. For example, often the sea falls or rises in an unusual manner prior to the major waves. In addition, often the first wave to hit is not the largest, allowing time for people to respond. A major problem with local-tsunami warnings is false alarms. Only a few of the seismic events capable of generating a tsunami will actually do so. Some officials feel that false alarms will undermine the effectiveness of the warning system. Another major problem with all tsunami warnings is that even if a tsunami is confirmed, the coastal run-ups vary markedly with location; thus, area-specific warnings are difficult to make.

1.2.4 Landslides

Ground failures caused by landslides and related failures cause billions of dollars in property losses in the United States each year (U.S. Geological Survey 1982). They exceed the annual combined losses from floods, earthquakes, hurricanes, and tornadoes by many times (Johns 1978). A variety of information is available that can be used to help manage this hazard, for example, through land use controls. In addition, potentially unstable land can be monitored so that populations at risk can be warned of an impending landslide. The most common types of monitoring are field observations, inclinometers, extensometers, and electrical fences or tripwires. There are also methods for monitoring rockfalls. Detection systems that measure increased potential for slope failure are being developed. This system uses a network of rain gauges coupled with empirical and theoretical models depicting the relationship between precipitation and landslide initiation to provide a real-time regional warning system (Keefer et al. 1987).

The Disaster Relief Act of 1974 required USGS to implement a warning system for landslides. USGS currently has three landslide warning categories. These are (1) a degree of risk greater than normal, (2) a hazardous condition that has recently developed or has only recently been recognized, and (3) a threat that warrants consideration of public response to an impending event. The time, place, and magnitude of impending landslides—the elements necessary for a public landslide warning—can be predicted only in areas that have benefited from detailed geological and engineering studies. There have been a few cases where such work that could lead to successful public warnings has been completed, as in California.

Landslide warnings currently remain a local responsibility, and no national landslide warning program is funded or is in place. USGS has called for an organized national program (U.S. Geological Survey 1982). Recent assessments do not rank landslide warnings as a high priority (Committee on Ground Failure Hazards 1985).

1.2.5 Hurricanes

Hurricanes occur in both the Atlantic and Pacific Oceans. The Gulf Coast, the Atlantic coast, and the Hawaiian Islands experience the greatest incidence of hurricanes. The National Weather Service (NWS), within the National Oceanic and Atmospheric Administration (NOAA), operates three hurricane centers which take the lead in issuing hurricane forecasts and warnings. These include the National Hurricane Center (NHC) in Miami, the Eastern Pacific Center in San Francisco, and the Central Pacific Hurricane Center in Honolulu. Most warnings are issued for Atlantic hurricanes through NHC. NHC issues bulletins, watches, and warnings regarding location, predicted path, intensity, timing, and probability of landfall. NHC cooperates in its hurricane prediction efforts with the Department of Defense, which assists in collecting data, tracking hurricanes, and issuing forecasts for military bases.

Three primary systems are used for issuing collecting information about hurricanes—weather satellites, reconnaissance aircraft equipped with special instrumentation, and coastal weather radar. A variety of models are used to predict hurricane paths and intensities. These are based on historical records of hurricane movement, short-term meteorological conditions, and dynamics of fluid and air movements, or some combination of techniques. Prediction also depends on the judgments of experienced forecasters. Models and judgments do not lead to precise forecasts of hurricane behavior, however. Considerable uncertainty and error exists in forecasts, and the greater the expected time before impact, the greater the uncertainty. Hurricanes are subject to abrupt, unpredictable changes in course. In addition, they can speed up, stall, or change in intensity, further complicating prediction.

Hurricane watches are issued by NWS about 72h before expected impact. Watches are issued for very large segments of coastal areas. At about 48h before landfall, the area to be alerted for a watch or warning can be narrowed to about a 500-mile section of coast. At 24h, the average forecast error gives a warning zone of from 200 to 250 miles. At each time period, NWS issues a probability that locations along the coast will experience landfall. These probabilities vary from a maximum likelihood of 10% at 72h to 35–45% at 24h.

When a hurricane is detected, NHC staff work with coastal offices of NWS in issuing local statements to inform the public about the hurricane. Detailed information is given in hurricane advisories and bulletins disseminated to media and state and local officials via NOAA Weather Wire, a dedicated teletype system, and over NOAA weather radio. Often NHC and local weather service offices are in direct contact with state and local officials.

After hurricane information has been issued by NHC, a variety of channels and methods are used to inform the public of the hurricane forecasts and to recommend protective action. Information comes from state and local officials, the media, or at times directly from NHC. It reaches the public through the media and from door-to-door contact. Often information from one source is inconsistent with another source. Warning content also changes over time as the behavior of the storm changes. Probabilities may increase, then decrease, and then increase again. A storm may veer in another direction, only to loop back in its original direction. Storms may parallel a coast and suddenly move ashore. Thousands or even millions of people may be at risk at some time from a storm. Those involved in hurricane warning systems therefore face many problems in achieving their goal of protecting public health and safety.

Warning systems for hurricanes are connected with hurricane hazard programs, which seek to define areas and populations at risk from storm surge and estimate evacuation times. The

studies growing out of these programs help officials know whom to warn and when those at risk need to be prepared to evacuate.

1.2.6 Tornadoes

Tornadoes occur in various parts of the world, but both the greatest number and most severe tornadoes are produced in the United States. Their origins can be traced to severe thunderstorms formed when warm, moisture-laden air sweeping in from the Gulf of Mexico meets cooler, continental air flowing from the west or northwest. Some of these thunderstorms are characterized by the violent updrafts and strong tangential winds that spawn tornadoes, though the details of tornado generation are still not fully understood.

Tornadoes are violently rotating columns of air suspended from cumulonimbus clouds. They begin as funnel-shaped extensions from the clouds and build downward to the ground and darken as they pick up debris. On a local scale, tornadoes are the most destructive of all atmospheric phenomena. Horizontal wind speed near the center of a tornado may exceed 300-mph, and the ground speed, usually 25–40mph, can range from almost stationary to nearly 70-mph. Paths of tornadoes can range in length from a few miles to several hundred miles and in breadth from a hundred yards to a few miles. In the United States, they generally move in a southwest to northeast direction. They are most prevalent in the spring and occur over much of the eastern two-thirds of the United States, with the highest frequency and greatest devastation experienced in the Middle South and the Midwest. Each year about 500 tornadoes are reported in the United States. They usually form during the middle or late afternoon, and the hours between 3 and 7 p.m. are the most likely period.

Not only are tornadoes only partially understood; they are also difficult to predict, owing to their rapid formation, short lifetime, and relatively small size. When meteorological conditions in a region may allow formation of tornadoes, a tornado watch is issued by NWS; when a tornado has been spotted or has been observed on weather radar, NWS issues a tornado warning.

NWS has statutory responsibility for providing a severe local storms watch and warning service (including tornadoes) for all 50 states. This watch and warning service, available to the general public and to aviation, is provided by NWS through its National Severe Storms Forecast Center (NSSFC) at Kansas City, Weather Service forecast offices (WSFOs), and Weather Service offices (WSOs). In the 48 contiguous states, NSSFC is responsible for issuing and cancelling severe thunderstorm and tornado watches and for alerting local forecast offices (WSFOs) to areas of high potential for severe weather development. Local offices, in turn, issue warnings based on actual sightings of tornadoes or on radar information. WSFOs and WSOs are responsible for informing the general public of potential severe weather and redefining the NSSFC statements for those parts of the states likely to be affected. When warnings are given, they are identified as either a tornado warning or a severe thunderstorm warning.

Weather radar is an essential tool in forecasting the severe weather from which tornadoes can be generated and in spotting actual tornadoes. The U.S. Basic Weather Radar Network (composed of NWS, the U.S. Air Force, and the Navy) operates a number of nonnetwork radars that are used primarily for local forecasting and warning and for providing selected information on severe storms. A planned national system of Doppler radars is now being developed under a joint program of the departments of Commerce, Defense, and Transportation. This program will produce the Next Generation Weather Radar, which is expected to allow more accurate and more

highly focused tornado forecasts, owing to its capability of measuring wind velocities within and around tornadoes.

In addition to radar information and satellite data (obtained through NOAA's National Environmental Satellite, Data, and Information Service), basic meteorological data required for NSSFC analyses include those obtained from the surface weather observational network, from rawinsonde (upper air measurement) stations, and from pilot reports of weather hazardous to aviation. NWS also uses observations of severe local weather, especially tornadoes, from citizen spotter networks, state highway patrols and local police departments, local civil defense organizations, cooperative NWS climatological observers, radio and television mobile units, many other employees of local governments, and individual citizens. These reports are received by various means and are not uniform at the various WSOs.

The principal NWS/NOAA systems for collecting and disseminating weather information are the automation and field operations, the radio report, the warning coordination circuit, the NOAA weather wire service (NWWS), and NOAA weather radio. The purpose of NWWS is to transmit consumer-oriented forecasts, watches, warnings, and meteorological data to the mass media for broadcasts to the public. WSFOs and WSOs equipped with NOAA weather radio can transmit weather information continuously to an area about 40 miles in radius. A tonal alert capability is used to activate specially designed NOAA radio receivers during severe weather conditions.

In addition, the National Warning System (NAWAS), which is operated by the Federal Emergency Management Agency (FEMA), can be employed at a time of weather emergency. NAWAS is a hot-line interstate telephone system that connects FEMA warning points with WSFOs, WSOs, and Weather Service Meteorological Observatories within each state and between states. The Emergency Broadcast System (EBS) can also be activated for tornado warnings. Because EBS is operated by individual radio and television stations, arrangements for its use are made before the severe local storm season or may be based on a continuing agreement.

Beside developing and issuing weather reports, NWS provides services involving technical assistance, advice, and consultation. Disaster preparedness assistance is designed to improve the response by community officials and the public to forecasts and warnings. Within available resources, such assistance is carried out by WSOs and warning preparedness meteorologists assigned to some WSFOs, primarily in the eastern, midwestern, and southern states. This NWS effort is coordinated at all levels with FEMA through a formal NOAA-FEMA Memorandum of Understanding.

1.2.7 Floods

NWS has responsibility for much of the nation's flood-warning activities and provides several different services to communities with flood problems, including forecasts and warnings. In addition to NWS, many communities in river basin groups provide local warning systems. These efforts differ between riverine and flash floods.

To predict riverine floods, the NWS has established river forecast centers for major river systems. These centers collect data from WSFOs and use computerized hydrological models to make flood forecasts for several different time frames. The forecasts are sent out to local NWS offices for dissemination to the public. Approximately 2000 communities affected by slow-creeping floods are included in this program.

NWS also provides general flash flood warning information to all counties in the United States. Two types of forecasts are made. A flash flood watch is issued if conditions indicate flash floods are likely to occur. A flash flood warning is issued when flooding is imminent or reported. These are only general warnings and do not contain detailed information about possible flood conditions. Some flood-prone communities receive more specific forecast information, such as information on flood locations and possible magnitudes, from WSFOs. In addition, communities and other local organizations (e.g., watershed planning districts) have developed localized warning systems based on available technology to provide their own forecasts. About 1000 communities nationwide have or are in the process of developing warning systems.

Local flood warning systems fall into two basic categories—manual and automated (Hydrology Subcommittee 1985). Each type has many variations, and many are unique systems. Flood warning systems follow four steps: collection of data, transmittal of data, analysis of the data and flood forecasting, and alerting of officials. The data that are collected include rainfall and stream data from a set of different locations upstream from the affected community. Data are transmitted to a centralized location, where they are analyzed for flood forecasts. The forecast, which generally includes timing and magnitude of the flood, is given to officials responsible for flood warning.

In manual systems, people are involved at all or almost all stages. They observe rain gages and call a weather office. The person at the weather office records the data and uses a forecast procedure to estimate flood characteristics. That person may then call a local emergency official if a flood is anticipated. An automated system may use a series of automated rain and stream gages to radio-transmit data to a central computer facility. These data are fed into a hydrological model. When a critical parameter is met, a beeper is activated to alert a local official. Some systems combine both manual and automated techniques (e.g., a single stream gage may be automated and linked to a beeper device, while other data are manually collected and analyzed).

Warnings are disseminated from NWS offices to local officials and over NOAA weatherwire (teletype). Local officials and the media further disseminate these warnings using EBS stations, television, cable, and other specialized warning-dissemination techniques.

1.2.8 Avalanches

Avalanche warning efforts result in informing the public of general avalanche conditions; specific warnings are especially directed to people outside controlled avalanche areas. Informal warning programs have operated in some states—for example, Colorado and Washington (Judson 1975; Williams 1980). A cooperative venture between NWS and the U.S. Forest Services (USFS) has sought to enhance avalanche warning efforts to disseminate warnings to back-country and mountain travelers.

A key component of the avalanche warning system is public education regarding avalanche risk in reference to zoning ordinances, ski-run closures, and highway restriction. Reports and warnings are transmitted to the media through NWS facilities. Further coverage is made through mountain NWS radio broadcasts, which are transmitted 24h a day. This coverage can include intermittent warnings when avalanche risk conditions are especially critical. Intermittent warnings can indicate moderate or high hazard. Moderate-hazard intermittent warnings classify avalanche risk that will most likely result from artificial releases at high elevations. High-hazard intermittent warnings indicate the possibility of larger avalanches

reaching populated areas and roads, and these warnings can also include hazardous lower elevations.

At present, avalanche warning systems are somewhat site-specific and include the participation of NWS and USFS. For example, the Colorado Avalanche Warning Program (CAWP) has operated for about a decade. Programs such as these rely on forecasted weather conditions from NWS and information on the snow pack from USFS. CAWP uses NWS and USFS in quantitative models to forecast local risk.

1.2.9 Nuclear Power Plants

Very precise guidelines have been established by FEMA and the Nuclear Regulatory Commission (NRC) on the design of a warning system for a nuclear power plant. The guidelines cover notification procedures, alerting methods, emergency communications, and testing (FEMA 1985).

FEMA and NRC require nuclear power plants to establish procedures for notifying state and local personnel about an emergency. The content of messages to officials and the public must be established, and there must be a means to provide early notification and clear instructions. Furthermore, these agencies require state and local governments to establish a system for disseminating to the public the initial and following information they receive from the plant via the appropriate broadcast media. The emergency plan must list the broadcast stations or systems with adequate signal strength and 24-h coverage that would be used. The procedures and individuals responsible for notification must be identified. Furthermore, the plan must address the time intervals for broadcasting official information. Federal guidance recommends a maximum interval of 15min. In addition, broadcasted information must be monitored and inaccurate information corrected.

The regulations require that each organization establish the administrative and physical means to notify the public within the emergency planning zone (EPZ) plume exposure pathway. It is left to the plant operators to demonstrate that the means exist, although state and local governments are responsible for activating a warning. The following procedures must be developed to demonstrate that the means of warning exist: (1)an organizational plan describing responsibilities and backup must be developed, and (2)a plan must be developed to activate the warning system to meet minimum warning times and to guarantee appropriate activation of the warning system.

The alert system must be capable of providing an alert signal and instructional information to the population within the 10-mile EPZ within 15min. The initial notification must have essentially 100% coverage of all people within 10miles. However, in extremely rural, low population areas beyond 5miles, up to 45min may be allowed for providing an alert signal and instructional message (FEMA 1985). Others beyond this distance that are difficult to alert within the given time limit are reviewed on a case-by-case basis. Warning plans must account for means of notifying special or institutional populations. The regulations do not require a set communication mode, so long as the above time requirements are met. Physical methods of communication include fixed or mobile sirens with EBS radio communication and tone-alert radios. In special cases, the use of existing institutional alert systems, aircraft, automatic telephone dialers, modulated power, or emergency personnel can be used. Other methods of communication (i.e., informal notification between members of the public) have also been included as part of warning plans.

Plans must also address communication among principal emergency response organizations and to the public. A communication plan must specify contacts and backups in each organization, and what primary and backup equipment is to be used. Plans must include provisions for 24-h notification to state or local officials. Provisions must be made for communication with all state and local governments in EPZ, federal emergency response organizations (including NRC), and all emergency operations facilities. Also, there must be provisions for activating emergency personnel in each organization.

Periodic exercises are required to test warning systems at nuclear power plants and to identify and correct any system deficiencies. In addition, telephone surveys of the population in EPZ are required to further confirm the altering capability of the system.

1.2.10 Hazardous Materials

Many federal agencies are involved in activities to reduce the risks imposed by hazardous materials; for example, major programs are conducted by the U.S. Environmental Protection Agency (EPA), FEMA, the U.S. Coast Guard, the U.S. Department of Transportation (DOT), the Occupational Safety and Health Administration, and NRC. The National Oil and Hazardous Substances Contingency Plan provides guidance on federal response to releases of hazardous material. Other enabling legislation includes the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (Superfund), the Resource Conservation and Recovery Act (RCRA), the Toxic Substances Control Act, the Clean Air Act, and the Clean Water Act.

1.2.10.1 Fixed Sites

In some cases fixed-site facilities that could release hazardous chemicals and threaten off-site populations and the communities in which they are located are required by federal legislation to develop emergency or contingency plans. For example, RCRA requires a spill contingency plan with a notification component before facilities can dispose of hazardous materials. More recently communities with facilities that store hazardous materials have been mandated to prepare emergency plans. Overall, the requirements in such legislation regarding warning systems are rather vague. As a result, existing warning systems have been developed primarily by individual companies or communities as a joint cooperative effort or through local requests or mandates.

National policies on emergency planning for chemical accidents evolved in the 1980s and are likely to have changed by the time this report is published. In 1981, FEMA and EPA published a joint planning guide which included the topic of warnings (FEMA/EPA 1981). Following the Superfund Amendments and Reauthorization Act (SARA) Title III legislation, EPA developed interim guidance on the Chemical Emergency Preparedness Program (EPA 1985). In 1987 the National Response Team (NRT) published the *Hazardous Materials Emergency Planning Guide* (NRT 1987), a joint effort of 14 federal agencies; this manual provides interim guidance as well as a framework for communities to work with plants in developing a warning system. FEMA is currently developing a guide for designing warning systems for hazardous material accidents.

These existing guidelines provide little detail about how to build a warning system for a chemical hazard, beyond recommending the development of a method to alert the public. This would include establishing a contact point between the plant and the community who would be

responsible for alerting the public and listing the essential data including health hazards, personal protection evacuation routes, shelters, and hospitals. Sirens, EBS radio, mobile public address systems, and house-to-house contact are recommended for warning the public.

According to the guidance (EPA 1985): "It is important to provide accurate information to the public in order to prevent panic." To this end, a single spokesperson should be used, and all warning activities should be deferred to this individual. Given the potential for urgency, warnings should be given via radio or television, not through newspapers. Any warning plan should evaluate how sirens will be used to notify the public and what geographical areas would be covered. Also, sample messages are recommended for general evacuation, school evacuation, and sheltering.

Industry has also developed a national program on emergency planning for hazardous material accidents called Community Awareness and Emergency Response, or CAER (CMA 1985). One product of this effort is a guide on community warning systems (CMA 1987).

In 1987 a survey was conducted on community warning systems for fixed-site chemical accidents (Sorensen and Rogers 1988) as part of the Section 305b report to Congress (EPA 1988). This survey found that few communities had state-of-the-art warning systems for both technology and management practices. The study concluded that the most effective way to improve warning systems was, first, to develop better plans and implementing procedures and, second, to disseminate improved warning technology.

1.2.10.2 Transportation

Each year there are some 6,000 to 15,000 accidents in the United States involving the transport of hazardous materials. Some of these pose a threat to the health and safety of the surrounding population and require warnings and subsequent protective action by members of the public. DOT regulates land transportation incidents regarding hazardous materials. When an accident occurs that may threaten public safety, the carrier in possession of the hazardous cargo is required to notify the DOT National Response Center hotline to report the incident.

Several other federal agencies can be involved in responses to a transportation accident involving hazardous materials. EPA maintains national and regional response centers with teams that are sent to sites of serious spills on land. The U.S. Coast Guard responds to incidents in ports and on water. The prime responsibilities of these teams are to provide technical assistance in containing and cleaning up spilled materials. The U.S. Department of Agriculture and the Public Health Service also respond to major incidents that exceed the capacity of state agencies. FEMA and other federal agencies also respond to incidents.

The prime responsibility for issuing a warning falls on local emergency response organizations, usually the state police, local sheriff or police, or fire department, that are the first to arrive at the scene of a spill. The primary warning problems that these organizations face are identifying the hazardous materials involved in an incident, determining the threat that they present, and then deciding who to warn and what to tell them. Some communities have developed plans to guide this activity, but most incidents require ad hoc responses.

To support warning efforts, DOT publishes a guidebook on emergency response for use in hazardous material incidents (DOT 1984). While this book gives no information on warnings, it does describe appropriate emergency actions for a variety of hazardous materials. The guide recommends that the on-the-scene commander contact CHEMTREC, a private emergency consulting service operated by the Chemical Manufacturers Association (1985), which maintains

a 24-h 800 telephone number. CHEMTREC provides advice on the materials involved and on how to handle the situation and immediately contacts the shipper of the materials for more detailed information and appropriate follow-up, including on-scene assistance. Often, CHEMTREC has to contact the manufacturer's representative before advice on substances can be provided.

Warnings regarding land spills are usually conducted on a door-to-door basis by law enforcement personnel or by the use of bullhorns on vehicles. Radio and telephone may be used as notification mechanisms in more protracted situations where the threats are less immediate. Thus, warning systems for this class of hazard are rather unsystematic and depend on ad hoc responses. Despite the lack of planning, numerous evacuations are successfully undertaken each year in connection with hazardous materials accidents.

1.2.11 Dam Failure

Dams can fail, causing downstream flooding, for a variety of reasons, including excess precipitation and runoff, structural failure, overtopping, or seismic activity. There are no major warning systems operated by the government for dam and reservoir systems. Warning systems for the nation's 10,000 dams, where they exist, are largely site-specific. For example, in Colorado warning and evacuation planning for dam failure is the domain of local governments. Recent efforts have attempted to increase the awareness of need for such warning systems (Division of Disaster Services 1985). It is believed that only a few communities in the nation have plans and warning capability; those that do probably exhibit a wide range in warning system structure and quality.

Several federal agencies with extensive reservoir systems—including the Corps of Engineers, the Bureau of Reclamation, and the Tennessee Valley Authority—are now developing warning systems guidance. The Corps of Engineers has developed prototype plans and planning guidance for its reservoirs. The Federal Interagency Committee on Dam Safety has developed emergency action planning guidelines for dams.

Dam warning systems are first tied to detection or prediction of possible failures. The means of detection are either from visual inspection or from such instruments as acoustic detectors, slope failure detectors, reservoir water level gages, or downstream flood detectors. Most dams rely on visual detection rather than instruments. Warning systems for dam failures may also be linked to events that lead to dam failure, such as floods or earthquakes. Particularly in the case of floods, the elements of a warning system may be very similar. Dam failure warnings can be issued through a variety of channels depending on the availability of communication and alert devices; little standardization exists.

1.2.12 Nuclear Attack

Nuclear attack poses difficult warning problems owing to the potential scope of the warning effort. The Civil Defense Warning System (CDWS) was developed to provide the means of warning federal, military, state and local officials, and the civilian population of an impending or actual enemy attack, accidental missile launch, or radioactive fallout. The CDWS combines national, state, and local resources. The heart of the system is the National Warning System (NAWAS) (FEMA 1981). Operated by FEMA, NAWAS is a series of nationwide dedicated telephone lines operated on a 24-h basis. NAWAS consists of two national warning

centers, ten regional warning centers, primary warning points, state warning points, extension warning points, and duplicate warning points.

A warning of nuclear attack would most likely originate from the North American Air Defense Command (NORAD), on the basis of tactical and strategic intelligence data (GAO 1986). This warning would be passed on to NORAD headquarters in Colorado Springs. An alternative National Warning Center is located in Maryland. The National Warning Center then simultaneously disseminates the warning to all NAWAS warning points.

Each state has a designated warning point operated on a 24-h basis and responsible for controlling warnings within the state. In addition, the NAWAS primary warning points and extension warning points include 400 federal points and 1600 city and county warning points. Primary warning points, staffed on a 24-h basis, are responsible for public dissemination of warnings. Duplicate warning points are staffed in emergencies and used when primary warning points cannot be in operation.

NAWAS is supplemented by state and local civil defense warning systems which transmit the warning to officials and the public. State civil defense offices are usually linked to other state agencies, county sheriffs, and civil defense agencies. Local civil defense officials transmit warning information to institutions and to the general public.

CDWS relies on outdoor siren systems and various forms of electronic communications, including commercial radio and television, EBS, cable television, group-alerting bell and light terminals operated by telephone companies, tone-alert radios, and public address systems. The outdoor siren system has two levels of warning. A 3-to5-min wavering tone is an attack warning and means an attack is in progress. A 3- to 5-min steady tone is an attention/alert warning and means that people should seek added information. The CDWS supports EBS, which is designed to get a single source message out to the public in the event of a warning. It can be activated by the president and could be used to disseminate a message from the president; however, the EBS system can be used by persons other than the president.

1.2.13 Terrorist Attack

The Federal Bureau of Investigation (FBI) defines terrorism as the unlawful use of force or violence against persons or property to intimidate or coerce a government, the civilian population, or any segment thereof in furtherance of political or social objectives. Such incidents traditionally have taken the form of armed attack on institutions, hostage seizure, planting explosives, or other forms of incursion designed to force cooperation from authorities in terms of publicity, release of prisoners, or monetary remuneration. Some four dozen terrorist incidents are reported within the United States annually, and this number might change in the future.

To our knowledge, no systematic, integrated warning plan has been developed to deal with a terrorist incident. It is likely that a large amount of strategic intelligence is collected about potential terrorist activities by, for example, the FBI, but how this information is processed and how a warning would be disseminated to appropriate officials or agencies is not public knowledge.

International police organizations such as INTERPOL maintain computerized files on terrorist groups and individuals. These may be used for pre-incident reference, incident management, and postincident assessment. Information technology serves a number of functions in this area, including crisis management, crisis simulation, analysis of essential terrorist elements, profile maintenance, and data storage and transmission.

Specific events and circumstances are often provided with unique warning system arrangements. In preparation for the 1984 Olympic Games, the Los Angeles Police Department established active intelligence networks and liaisons with other agencies in the U.S. antiterrorist community, and reportedly conferred with British, West German (Chartrand 1985), and Israeli intelligence services. During the 1984 U.S. presidential elections, the FBI and the Secret Service collaborated to protect presidential candidates. Persons who were considered potential threats to the candidates were registered in the National Crime Information Center files, which are automated and readily accessible.

1.3 REPORT ORGANIZATION

This report is divided into four general parts. In the first part (Sects.1 and2), we describe and define a warning system. The first section described existing warning systems in the United States. Section2 is a conceptualization of the generic components of all warning systems. In this section, we note that all warning systems are divided into a detection or technical component (monitoring and detection, data assessment and analysis, prediction, and informing); an emergency management component (interpretation, decision to warn, method and content of warning, and monitoring of response); and a public response component (interpretation and response). We also address the method and content of informal warnings and the divergent viewpoints regarding what a warning system is.

Section3 constitutes the second general part of the report. In this section, we offer a set of practical recommendations for planners to consider when building, maintaining, or evaluating a public emergency warning system. We believe that these recommendations are based on solid empirical evidence. While we caution readers that we are researchers and are not well-versed in the political realities of regulatory agencies or governmental jurisdictions, nevertheless, political realities and the ideal-type of warning system we propose in Sect.3 can be integrated to take full advantage of the knowledge accumulated in this area of research.

The third part of this report—covering Sects.4, 5, and 6—addresses the reasons why an ideal-type emergency warning system might look like the system proposed in Sect.3. In Sect.4, we present research findings on why a warning system can be less than totally effective from an organizational viewpoint. It is clear, for example, that uncertainties regarding the impending event, the parties with whom to communicate, and impacts perceived to be associated with a false alarm are the major organizational obstacles to warning system effectiveness. We also offer planning strategies to reduce these problems. Section5 reviews research on public response to warnings. This section proposes that warnings determine what members of the public perceive their risk to be in a warning event and that these situational risk perceptions are the key determinants of actual response to warnings. We then catalogue research findings that have been found to explain variation in risk perception and warning response. The topic of Sect.6 is how differences and similarities across hazard types—in terms of relevant warning system and response concepts—suggests overlap and differences in warning system plans. Our conclusion is that overlap across warning systems is warranted, but that complete overlap across all warning system types is probably not possible.

In Sect.7, we summarize current research needs based on the state of knowledge regarding the public response, organizational, and practical aspects of public emergency warning systems.

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2. DEFINITION OF A WARNING SYSTEM

A warning system is a means of getting information about an impending emergency, communicating that information to those who need it, and facilitating good decisions and timely response by people in danger. This definition is simple but accurate. Contemporary warning systems are not simple systems, however. They are complex in both organizational structure and work process. They tie together work in a variety of specialties within and across many different organizations. For example, they can link science, technology, levels of government, and the public.

It is possible to reduce the organizational and functional complexities of warning systems to a set of relatively simple concepts and relationships. It is the purpose of this section to describe these and comment on how they work in practice. First, we describe the general structure of a warning system and its subsystems. Second, we examine the components of each subsystem, with attention to process, major issues, dilemmas, and problems. In addition, we consider informal warnings. Finally, we discuss divergent views on warning systems. We suggest that these divergent views must be merged to achieve integrated warning systems.

2.1 SYSTEM STRUCTURE

The structure of warning systems has been researched and discussed for several decades (Moore et al. 1963; Williams 1964; McLuckie 1970; Mileti 1975; Perry, Lindell, and Greene 1981; Lehto and Miller 1986; Rogers and Nehnevajsa 1986). There is a large degree of consensus among researchers about the structure of a warning system and how variation in a system's structure can alter its effectiveness. The most effective structure for a warning system is that of an integrated system. An integrated system has two qualities that make it unique. First, to ensure preparedness, the warning system is composed of three relatively separate subsystems, the detection, management, and response subsystems. Second, integration requires that sound relationships among these subsystems be developed and maintained.

2.1.1 The Detection Subsystem

The detection subsystem focuses on the relatively routine monitoring of the natural, technological, and civil environments that could induce an emergency. It collects, collates, assesses, and analyzes information about those environments and, when warranted, makes a prediction about the potential occurrence of an emergency. The prediction is then communicated from the detection subsystem to the management subsystem. This typically means that scientists inform emergency management officials about impending natural emergencies. Military, police, or intelligence organizations typically inform civilian officials about civil emergencies.

The detection subsystem is largely the domain of scientific organizations for natural hazards. For example, NWS performs this function for hurricanes and USGS does it for volcanoes. Scientists also perform this function for most technological hazards. For example, radiation health physicists and others would assist in estimating off-site risk in a nuclear power plant accident. For civil hazards the detection subsystem involves other groups. For example, the military perform the detection function for nuclear attack. It is also possible that members of

the public can play a role in the detection subsystem, for example, by sensing and interpreting environmental cues about a hazard and then informing others.

The hazard type does not alter the basic functions of the detection subsystem, which are to detect the presence of a potential emergency and then inform those who must manage the event. In an integrated warning system the detection subsystem has specific structural characteristics. First, the environment-detection linkage is clear and routine. Second, the link between detection and the management subsystem is clear and familiar.

2.1.2 The Management Subsystem

The second subsystem is focused on integrating the risk information received from the detection subsystem and warning the public when warranted. This subsystem is composed largely of local emergency management officials. After receiving information from the detection subsystem, these managers must interpret that information in terms of potential losses (e.g., loss of life and property) and then decide if the risk warrants a public warning. In making such decisions, managers use specified or ad hoc criteria. Official public warnings are made following a positive decision. One part of this subsystem often overlooked is the monitoring of public response once warnings are issued so that subsequent warnings can be refined or changed if people are not responding in a way that would minimize their exposure to risk.

The management subsystem of a warning system is typically the domain of local government. For example, a mayor or county executive is usually responsible for issuing evacuation advisements for floods. Occasionally warning the public is the responsibility of a governor as, for example, in the case of nuclear power plant accidents in some states.

Ascription of management responsibility across type of government and variation in hazard type has little if any effect on the major objectives of this subsystem, which are always to interpret risk information and then inform the public. The management subsystem has particular structural characteristics in an integrated warning system. First, the linkage between the detection and management subsystems is clear and familiar. Second, because managers may need assistance in interpreting risk information, there is communication between detection and management subsystem personnel. Third, the link to the public through actual warnings and monitoring of response is comprehensive and informed, not ad hoc. Finally, the ability of the environment to bypass the detection subsystem and directly influence managers is recognized and incorporated into plans. For example, it can be difficult to issue flood warnings on a sunny day when there are no environmental cues. This constraint can be overcome through planning.

2.1.3 The Response Subsystem

Public response constitutes the third warning subsystem. People respond to warnings received from the management subsystem on the basis of their own interpretations of those warnings, and public interpretation can differ from that of detectors or managers. Moreover, the public response subsystem contains an additional warning element, in that people generate unofficial warnings for others. Unofficial warnings can come from members of the management subsystem, for example individual fire and policemen who choose to go house-to-house or from members of the warned public who inform others. People also confirm and alter warnings according to their own perception of events and their own social realities. This facet of a warning system can be overlooked in preparedness.

The ideal response subsystem has particular structural characteristics in an integrated warning system. First, comprehensive and multiple channels of communication to the public have been prepared. Second, warning messages are comprehensive and provide the public with all that it needs to know. Third, public response is monitored as it occurs and fed back into the management subsystem so that adjustments in warnings can be made as needed. Fourth, the ability of the environment to bypass the detection and management subsystems and directly influence public response is taken into account in planning. For example, warnings can explain that the potential for emergency exists despite a lack of obvious environmental cues. Finally, the possibility that detection-system personnel may informally give to the public direct information, which supports or contradicts official warnings, is recognized and managed.

2.1.4 An Integrated Warning System

The model proposed in Fig.2.1 recognizes multiple warning subsystems and formal as well as informal linkages between them. Two of the greatest constraints to effective emergency warnings are a lack of integration among warning subsystems or a lack of recognition of all subsystem linkages.

2.2 SUBSYSTEM COMPONENTS AND PROCESSES

Each subsystem in a warning system has its own processes to accomplish work and achieve special objectives. These processes have associated issues, dilemmas, and problems. It is the purpose of this section to describe these subsystem processes and components.

2.2.1 The Detection Subsystem

The processes related to detecting an impending emergency largely involve the use of technology and/or science. Scientists and technicians have increasingly played roles in hazard detection as the amount and sophistication level of detection technology has advanced. Members of the public still play a role in hazard detection through sensory observations reported to others. Here, we review the general role of the detection subsystem and some of the problems that can arise when it is used.

2.2.1.1 Monitoring and Detection

The first function of the detection subsystem of a warning system is to collect data about the presence of hazards. This is done both systematically and serendipitously. The systematic approach involves regular observation, measurement, and recording of information about factors that could indicate an impending emergency. The serendipitous approach involves nonsystematic observation of factors which may occur by chance for nonhazard assessment purposes, or by hunch and intuition. Serendipitous observations can be made by members of monitoring organizations and by the public. Both approaches produce data that can be used to predict emergencies.

It is most common for official warnings to originate from the systematic monitoring and data collection approach. For example, instrumentation is in place in some parts of California to collect data for earthquake prediction and warning, rainfall gages are used locally to estimate

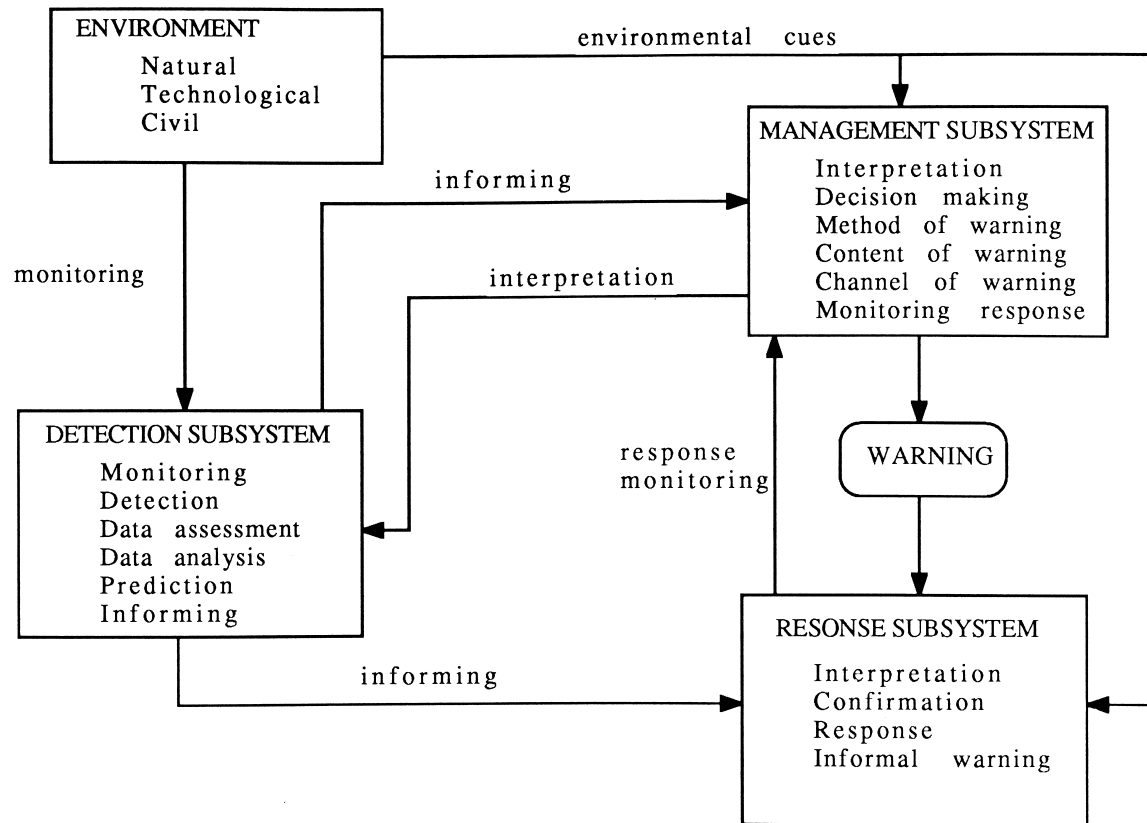


Fig. 2.1. The general components of an integrated warning system.

runoff volumes in flood forecasting, an extensive array of instrumentation is used to detect transient events in nuclear power plants, and tactical and strategic intelligence data are gathered to detect nuclear attack. Sometimes impending emergencies are detected serendipitously. For example, warnings for mudflows along coastal areas frequently are made only after an initial event has occurred and others are likely.

The major issue surrounding monitoring and detection is how much information is needed to detect an impending emergency. The answer to this question hinges on a number of factors including the complexity of the hazard system being monitored, the adequacy of scientific theory or intelligence to predict an emergency, the type of data assessment that must be performed, the level of confidence desired in that analysis, and the resources available to support detection and warning. These needs vary among hazard types and locations.

Monitoring and detection are based on the recognition of some indicators of an impending emergency. For example, in a flood, recognition may be based on observing rainfall and rising river levels. At a nuclear power plant, it may be a combination of instrument reading and alarms. For an earthquake, it may be a swarm of small, precursory seismic events. Regardless of hazard type some signs must be read and interpreted before the first steps toward public warning are implemented. Detection may be made by a member of the public, as in the case of a hazardous chemical spill from a truck, or it may be performed by a specialized monitoring organization, such as NWS or NORAD, through the use of sophisticated technological equipment.

2.2.1.2 Data Assessment and Analysis

The second stage in the detection subsystem of warning systems is data assessment and analysis. Its purpose is to use data to understand the behavior of the hazard system being monitored. This can be done with a fixed set of ideas or theory about that system, or through a screening process that indicates anomalies.

The methods of data assessment range from simple computations to complex modeling efforts. Data inputs range from single variable indicators to complex sets of multiple variable indicators. For example, the assessment of local-tsunami potential is determined by the single variable of earthquake magnitude. At the other extreme, complex multiple variables are used to analyze some flood flows, and nuclear power plant accidents are simulated in complex ways. Nuclear attack could be assessed from single indicators or complicated computer assessments.

Data analysis in warning systems is limited by the factors that bound inquiry. First, limits are imposed by the adequacy of available data. For example, the analysis of hurricanes near Hawaii is complicated by the lack of local weather radar information. Second, data analysis is limited by the level of development in relevant theory. For example, earthquake prediction is currently constrained by the absence of a universally accepted theory of strain release along faults. Third, data analysis can be limited by experience. Insufficient historical records may inhibit understanding of the system being analyzed. The experience of personnel may limit the choice of the type of analysis performed. Fourth, analysis of data is limited by resources. For example, it is impossible to analyze seismological data for every active volcano; it is impossible to simulate the movement of carcinogens into groundwater supplies from every known hazardous waste site.

Several issues complicate data analysis for warnings. First, there is the issue of the legitimacy of the analysis. The scientific basis of the analysis is often not well demonstrated. The experience with earthquake predictions illustrates this problem. A recent prediction for Peru

could not be scientifically validated or disproved. Second, there is the issue of multiple analyses and the need for concurrence in conclusions. Both of these issues demonstrate the need for peer consultation, review, and endorsement by a respected scientific reference group.

Once a hazard is detected, the next decision in the warning process is whether or not it poses a threat to human health and safety. In a nuclear attack this threshold may come before actual missile launches are detected. In a flood this threshold may be defined as waters exceeding flood-stage elevations. It may be defined as an off-site release at a nuclear power plant. In an earthquake prediction it may be indicated by an expected Richter magnitude of energy release and associated shaking intensities in populated areas. The determination of threat is often done by the same person or organization performing the detection. Different actors and organizations may also be involved, including private citizens, companies, or any level of government. For example, USGS is formally charged with issuing hazard watches and must detect and assess threats from geologic hazards. The state of California determines whether or not an earthquake prediction is valid and constitutes a threat to the public. Local governments often must determine whether a derailed train carries hazardous materials. Public and private utilities must determine dose projections in the event of a nuclear power plant accident. Police departments assess the level of public threat in civil disorders. Threat determination is judging that an event is or is not hazardous to the public.

The collation and evaluation of information concerning the hazard are usually performed by a formal organization for which such tasks are part of its normal operations. Such organizations usually convey threat information to emergency management groups within the endangered community. They, in turn, disseminate warnings to the public.

2.2.1.3 Prediction

The purpose of the prediction function in a warning system is to forecast the behavior of the hazard system in a way useful for providing a warning of impending disaster. Predictions for use in warning systems are best if they include information on five factors: (1) lead time, or when the disaster will occur; (2) location, or the area to be impacted; (3) magnitude, or how large (measured in physical variables of the system); (4) probability, or the likelihood it will take place; and (5) consequences, or physical effects.

A variety of formal and informal methods are used in prediction. Prediction is limited by many of the same factors which limit data analysis. These includes data, theory, experience, resources, and expertise. In addition, prediction is complicated by the issues of confidence and uniqueness. Predictions contain varying uncertainties even when stated in probabilistic terms. The basic problem is deciding when uncertainties are small enough to be confident that the prediction is accurate. Prediction may be confounded by the uniqueness of the event when compared to the universe of events of its type.

2.2.1.4 Informing

If predictions are to become part of the warning system, they must go beyond those who detect a hazard and be communicated to emergency management officials. This communication was labelled as informing in Fig.2.1.

Informing can rely on formally established procedures, which provide guidelines on when, how, who, and what to inform. For example, NWS may have formal arrangements with local media for issuing tornado warnings. Information can also be an informal process for which the responsibility rests on the personnel formulating the prediction. The communication of an imminent landslide may come only at the judgment and disposition of the earth scientist. In either case, responsibility is at the heart of the informing function. Responsibility is sometimes legislatively mandated. This is the case for the U.S. Geological Hazards Program and for nuclear power plant emergencies. In other situations, it is the result of contractual or prearranged agreements. Sometimes the burden lies on informal, ad hoc arrangement, which can, on occasion, create problems for all involved.

The effective transmission of predictions from detectors to emergency managers has not always occurred in past emergencies. The process of informing emergency managers has often been constrained due to several factors. One factor has been concern by detectors of being wrong, for example that the disaster will not occur. This sort of concern has resulted in delays in informing emergency managers about risk. A second factor that has constrained informing is communication focused. For example, detectors inform emergency managers in technical or scientific terms which are less than clearly understood; it is not obvious to the detector to whom in the emergency management community the communication is best addressed; or communication hardware is inadequate, unavailable, or broken. These factors have also resulted in communication delays in informing emergency managers.

Once a threat is judged to be a significant one, the detector must decide whether or not to alert others about the risk and potential damages. Part of this decision includes determining who should be informed. Clearly, for some hazards—for example, nuclear power plant accident—the alert decision is spelled out in plans. The decision remains discretionary for other hazards. In most warning systems information is usually passed on to an agency with emergency powers or responsibilities through, for example, a phone call to a police dispatcher, an automatic ring-down to a civil defense director, or an activation of a tone-alert radio in the mayor's home. These same communications often occur in an ad hoc manner when not part of formal preparedness.

2.2.2 The Management Subsystem

Official emergency managers typically take the lead in issuing warnings to the public. Public warnings can also be issued by people and organizations without official warning roles. Research has demonstrated that officials who provide the public with warnings come from both formally recognized disaster response organizations and from groups whose warning roles emerge during the emergency. For example, when Mount St. Helens erupted, both the USGS (which had mandated responsibilities to provide warnings) and the Forest Service (which assumed that responsibility) were part of the emergency management component of the warning system.

2.2.2.1 Interpretation

Scientific data, analyses, and predictions are of varying use to an emergency management official who seeks to perform a warning system role. This variability occurs because some of the information provided by detectors cannot be used to make decisions about warning the public, some cannot be incorporated into the warning content, and some cannot be understood at all. The burden of converting risk information into relevant facts often falls on the emergency managers and frequently involves communication and negotiation with scientists or technicians. Negotiation is used because often the detector does not express predictions in the terms a public official wants or can use. For example, earth scientists monitoring an erupting volcano may provide officials with projections of the movement of molten lava based on harmonic tremors. What the official might want to know is where that lava will flow, the length of time it will take to get there, and what the effects will be. The emergency management component of a warning system typically demands different information than the detector is able to provide or is confident in providing.

At times emergency managers can have a difficult time understanding hazard predictions particularly if they are offered by scientists. For example, local sheriffs responsible for sounding a siren in the event of a hazardous chemical release may not be able to decide on the basis of projected population or individual level doses. Indeed, a sheriff may not know the difference between the two measures. More interpretive information is usually necessary because uncertainty and confusion produced by misunderstood information can lead to inappropriate decisions.

2.2.2.2 Decision to Warn

The critical question facing emergency managers once apprised of a threat is, does the public need to know? Surprisingly, the decision to warn the public is one of the least understood aspects of warning systems. One major issue concerns specifying who makes the decision to warn the public. The decision may be made by a single individual or by a group of individuals. It may be carried out in interpersonal settings or in more rigid institutional environments. It may not be clearly specified who makes the decision in some cases, while in others it may be highly formalized. Previous experience with warning decisions does not clearly illustrate which type of arrangement works best; it does make clear that the person or group making the decision should be identified and recognized before the decision is needed.

A second issue is how to decide. If a single person makes the decision, should he or she do so with consultation? In a group, is consensus, a majority, or even a minority-held belief needed for a warning to be issued? What criteria should be used? Is a recommendation by a scientist necessary? Do predetermined conditions trigger the warning? How much certainty is needed in predictions? Is the decision influenced by the potential magnitude of the impending emergency? Is it sensitive to political concerns? Past experience indicates that answers to questions like these are important parts of the decision process.

The fear of being wrong often surrounds the decision to issue a public warning. This can stem from several factors, such as the fears of being embarrassed, causing public panic, and effecting unnecessary social and economic disruption. Fear can affect the timing of warnings. There are some valid reasons for delaying the issuance of a warning to the public. During a delay, more information can be gathered to validate the need for a public warning. Also, there may be

concern that people will not heed the warning if the threat is not immediate. These concerns must be traded off against a growing concern about the consequences of not warning. There are both legal and moral facets to this concern. Can officials be held responsible for withholding information? Is it ethical to withhold the warning? Obviously, public death and injury can result if withheld warnings are followed by disaster.

2.3.2.3 Method and Content of Warning

The aim of a public warning is to alert the public to the likelihood, nature, and consequences of an impending disaster and outline appropriate protective actions. People not at risk as well as those at risk need to be informed, for it is important to know that one is safe from an impending threat.

The method and content of warning consists of the warning message itself, the source of that message, the channels by which it is communicated, and the frequency with which it is repeated. Messages are sometimes written before hand and read when needed. At the other extreme, messages are delivered extemporaneously with little forethought.

Past experience has shown some types of messages to be more effective than others. Good messages contain consistent, accurate, and clear information; guidance on what to do; risk locations; and confidence or certainty in tone. In general, messages must come from sources that the public view as credible. Because different people have different views of credibility, it is usually desirable for messages to come from multiple channels and sources. These include channels such as sirens, the media, emergency broadcast stations, personal contact, or such special systems as automatic telephone ring-downs and tone-alert radios. Multiple sources would include scientists, engineers, public officials, volunteer disaster organizations, or community opinion leaders. Another dimension of warning is the frequency of message dissemination. A single warning is not sufficient to get people to believe and respond.

2.2.2.4 Monitoring Response

One of the most neglected aspects of the emergency management component of warning systems is the monitoring of public response to warnings issued. It is important that those issuing public warnings have some notion of what effects the warnings are having, how the public is interpreting the information, and what additional information is being generated outside the official warning channels. The results of monitoring can be used to adjust the warning method or content on the basis of what the public is and is not doing and to dispel inaccurate warning information.

Rarely does a warning system formalize this mechanism beyond passive rumor control headquarters that the public can call to confirm or disprove rumors. On the other hand, a good system would actively monitor people and the media to correct problems before they become widespread or rumors become rampant.

2.2.3 The Response System

It is often easy for detectors, particularly if they are technicians, scientists, and emergency managers to lose sight of the "big picture" when a warning system is activated. Warning systems are not scientific experiments in which theories, hypotheses, and probabilities

about occurrence are scientifically tested, but often scientists involved in warning systems view them in this way. Warning systems are also not exercises in carrying out bureaucratic procedures to honor mandated responsibilities and not exceed the limits of particular political roles and jurisdictions. Emergency managers can see them in this way. Warning systems are the means to serve the larger goal of protecting public health and safety in times of impending emergencies. As such, warning systems exist to help an endangered public take protective actions before a disaster strikes and to convey reassurance to other people not at risk.

Several factors need to be understood and used in warning system preparedness to help elicit a sound public response. Among these are, first, knowledge about how people interpret warning information, and, second, the process through which people come to respond to warning information.

2.2.3.1 Interpretation

Objective reality is not "reality" for people. What is "reality" for people is what they believe or perceive to be real. Consequently, perceptions of reality by people need not match objective reality. In an emergency, this means that even though everyone may be listening to the same warning information message, different people can reach different conclusion about what they hear. These different perceived "realities" about the emergency lead to differing public responses to the same warning message. Some responses can enhance protection while others may not. This problem can be avoided by constructing public warnings so as to help all members of an endangered public perceive reality in the same way; those perceptions can approximate objective knowledge about the impending risk.

The process whereby people act on the basis of their interpretations of emergency warning information can be described in the following way: people must hear the message that is given, it must be understood, it must be believed, and it must be personalized. People must then decide to do something, and, finally, people must carry out their response decisions. Of course, there are exceptions to this process.

Portions of a public can exit from the process at any of these stages. For example, some may understand what is being said in a warning, but they may not believe what they hear. Some may believe what they hear but not personalize the risk—that is, they may not think that they themselves are among those at risk. In addition, some may decide to respond but not be able to actually do so because they lack a means for carrying out their decision. Constraints to effective public response exist at each step in the response process. Indeed, the goals of any public warning system are (1)to have everyone who should hear a warning message hear it, (2)to have all members of the public understand what is being said, (3)to have the public believe what is being said, (4)to have people at risk personalize the warning information and those not at risk not do so, (5)to have people come to make good decisions about what they should and should not do, and (6)to have people act or respond on the basis of those decisions in a timely fashion.

2.2.3.2 Response

What people do in response to emergency warnings varies. They might evacuate, bring lawn furniture inside, close windows, or seek more information about the impending emergency. People can and often do engage in multiple responses to warnings.

Unfortunately, it is not always clear what are the best steps to take in response to emergency warnings. Judgments about response can be different in hindsight. For example, sheltering in-place might seem to be a good response to hurricane warnings, but may be a wrong decision in hindsight if the shelter is damaged or destroyed. The adequacy of responses might be measured in several ways, for example, the extent to which people react in ways consistent with the emergency information that they were provided or the number of deaths and injuries avoided.

2.2.3.3 Informal Warnings

There is an informal dimension to emergency public warnings. People who are the targets of formal warnings also participate in warning others. These informal warnings can serve a useful purpose. For example, people often contact relatives, friends, and other intimates to warn them or make sure that they have been warned. Informal warnings can also be accidental or result from behavior not intended to share warnings with others. For example, an initial first-warning response is to seek more information and confirm the initial warning, and people often contact others in this seek and confirm process. Some of these contacts spread warnings to persons not yet aware of the emergency. The result of either type of informal warnings is that people in the public help to warn others.

Sometimes informal warnings are correct and help to reinforce official warnings. Other times informal warnings can be incorrect. This is more likely when there are strong pre-emergency misperceptions about the hazard, as, for example, that nuclear power plants can explode like bombs, that lightning never strikes in the same place twice, or that it never floods on the south side of town. Informal warnings can contribute to confusion in these cases, particularly if formal warnings are weak in substance or form.

Some empirical warning studies have provided data on the incidence of informal notification in historical emergencies (Table 2.1). While no study has explicitly focused upon the phenomenon, the available data suggest several conclusions.

First, informal notification does occur in emergencies. It is likely that most members of the public engage in some behavior after being warned that could result in spreading warnings to others. Data in Table 2.1 suggest that a median of 38% of those warned received their first warnings by informal notification. Attempts to estimate public alert rates are likely to underestimate notification times if they do not take informal notification into account. The role of informal notification in providing first warnings would probably decrease dramatically as the speed of the formal alert and notification system increases. Informal notification also appears to increase as the urgency of the situation increases. Finally, almost 90% of those warned received informal notification in historical emergencies.

2.3 MERGING DIVERGENT VIEWPOINTS FOR INTEGRATED WARNING SYSTEMS

Many different people and organizations perform roles in a warning system. These people may be members of organizations with formal warning duties, members of organizations whose warning roles emerge during the emergency, and members of the general public. Organizational membership and professional specializations can cause people to view the general warning system differently. Different views of the same system by different actors can constrain system effectiveness.

Table 2.1. Reported rates of informal notification

Event	Informal notification			Time of first warning	Lead time	Hazard type	Reference
	Received as first warning	Received as any warning	Gave to others				
Hilo Tsunami	-	17%	-	Evening	Short	Tsunami	Lachman et al. 1961, p. 11
Denver Flood	28%	40%	-	Afternoon	Short	Flood	Drabek and Stephenson 1971, Drabek 1969
Canadian Explosion	62%	-	-	-	Short	Explosion	Scanlon and Frizzell 1972, p. 316
Hurricane Camille	-	81%	-	Morning	Long	Hurricane	Wilkinson and Ross 1970
Abilene Flood	25%	-	87%	-	Medium	Flood	Perry and Mushkatel 1986
Mt. Vernon Hazard Material	44%	-	68%	Morning	Short	Haz Material	Perry and Mushkatel 1986, p. 32
Denver Hazard Material	58%	-	27%	Evening	Short	Haz Material	Perry and Mushkatel 1986, p. 32
Alaska Tsunami	14%	-	-	Afternoon	Short	Tsunami	Haas and Trainer 1973, p. 32
Mount St. Helens, Toutle	41%	-	-	Morning	Short	Volcano	Perry and Greene 1983, p. 51
Mount St. Helens, Woodland	59%	-	-	Morning	Short	Volcano	Perry and Greene 1983
Hurricane Eloise	-	65%	-	-	Long	Hurricane	Windham et al. 1977, p. 38
Pittsburgh Hazard Material	18%	-	30%	Afternoon	Short	Haz Material	Rogers and Sorensen 1989
Confluence Hazard Material	18%	-	32%	Night	Short	Haz Material	Rogers and Sorensen 1989
Los Angeles Earthquake	-	83%	73%	-	Long	Earthquake	Turner et al. 1986, pp. 66, 70-71
Prediction	-	-	-	-	-	Prediction	-
Mount St. Helens Ashfall	52%	-	15%	Day	Long	Ashfall	Dillman, Schwabe, and Short 1983
Mount St. Helens	38%	-	-	Morning	Long	Volcano	Perry 1985, p. 92.
Fillmore Flood	39%	-	-	Morning	Short	Flood	Perry, Lindell, and Greene 1981
Three Mile Island	24%	-	-	-	Long	Nuclear Power Plant	Perry 1985, p. 41
Worcester Tornado	-	-	40%	Afternoon	Short	Tornado	Wallace 1956, p. 39
Valley Flood	38%	-	-	Evening	Short	Flood	Perry, Lindell, and Greene 1981
Snowquaimie Flood	43%	-	-	Night	Short	Flood	Perry, Lindell, and Greene 1981
Sumner Flood	89%	-	-	Morning	Short	Flood	Perry, Lindell, and Greene 1981
Eagle Pass Flood	32%	-	-	Morning	Long	Flood	Clifford 1956, p. 114
Piedras Negras Flood	15%	-	-	Morning	Long	Flood	Clifford 1956, p. 114
Nanticoke Hazard Material	38%	58%	-	Night	Short	Haz Material	Duclos, Binder, and Reister 1989
Hurricane Carla	6%	-	-	-	Long	Hurricane	Moore et al. 1963
Air Raid	-	-	4%	Night	Short	Air Raid	Mack and Baker 1961, p. 13
Mississauga Derailment	24%	-	-	Morning	Short	Haz Material	Burton et al. 1981, p. 5-46
Mobile Hurricane	-	-	19%	-	Long	Hurricane	Leik et al. 1981, p. 189
Miami Hurricane	-	-	21%	-	Long	Hurricane	Leik et al. 1981, p. 189
New Orleans Hurricane	-	-	15%	-	Long	Hurricane	Leik et al. 1981, p. 189
Atlanta Flood	-	-	4%	-	-	Flood	Leik et al. 1981, p. 189
Boise Flood	-	-	23%	-	-	Flood	Leik et al. 1981, p. 189

Table 2.1. (continued)

Event	Informal notification			Time of first warning	Lead time	Hazard type	Reference
	Received as first warning	Received as any warning	Gave to others				
Wheeling Flood	-	-	12%	-	-	Flood	Leik et al. 1981, p. 189
Rochester Flood	-	-	13%	Night	Short	Flood	Leik et al. 1981, p. 189
Clarksburg Flood	-	-	21%	-	-	Flood	Leik et al. 1981, p. 189
Minneapolis Tornado	-	-	5%	-	Short	Tornado	Leik et al. 1981, p. 189

Sources: I. Burton et al., *The Mississauga Evacuation: Final Report*, Institute for Environmental Studies, Univ. of Toronto, Toronto, 1981; R. A. Clifford, *The Rio Grande Flood: A Comparative Study of Border Communities in Disaster*, Disaster Study 7, National Research Council, National Academy of Sciences, Washington, D.C., 1956; D. Dillman, M. Schwalbe, and J. Short, "Communication Behavior and Social Impacts Following the May 18, 1980, Eruption of Mt. St. Helens," *Mt. St. Helens: Three Years Later Conference Proceedings*, Washington State University, Pullman, Wash., 1983; T. E. Drabek, "Social Processes in Disaster: Family Evacuation," *Social Problems* 16 (Winter), 336-49 (1969); T. E. Drabek and J. S. Stephenson III, "When Disaster Strikes," *Journal of Applied Social Psychology* 1(2), 187-203 (1971); P. Duclos, S. Binder, and R. Reister, "Community Evacuation Following the Spencer Metal Processing Plant Fire, Nanticoke, Pennsylvania," *Journal of Hazardous Materials* 22, 1-11 (1989); J. E. Haas and P. Trainer, "Effectiveness of the Tsunami Warning System in Selected Coastal Towns in Alaska," paper presented at the 5th World Conference of Earthquake Engineering, Rome, June 1973; R. Lachman, M. Tatsuoka, and W. Bonk, "Human Behavior During the Tsunami of May 1960," *Science* 133, 1405-09 (May 5, 1961); R. K. Leik et al., *Community Response to Natural Warnings*, University of Minnesota, Minneapolis, 1981; R. W. Mack and G. W. Baker, *The Occasion Instants: The Structure of Social Responses to Repeated Air Raid Warnings*, Disaster Study 15, National Research Council, National Academy of Sciences, Washington, D.C., 1961; H. E. Moore et al., *Before the Wind: A Study of Response to Hurricane Carla*, Disaster Study 19, National Research Council, National Academy of Sciences, Washington, D.C., 1963; R. W. Perry, *Comprehensive Emergency Management: Evacuating Threatened Populations*, JAI Press, Greenwich, Ct., 1985; R. W. Perry and M. R. Greene, *Citizen Response to Volcanic Eruptions: The Case of Mt. St. Helens*, Irvington Publishers, Inc., New York, 1983; R. W. Perry and A. Mushkatel, *Minority Citizens in Disaster*, University of Georgia Press, Athens, Ga., 1986; R. W. Perry, M. K. Lindell, and M. R. Greene, *Evacuation Planning in Emergency Management*, Lexington Books, Lexington, Mass., 1981; G. O. Rogers and J. H. Sorensen, "Warning and Response to Two Hazardous Materials Transportation Accidents in the U.S.," *Journal of Hazardous Materials* 22, 57-74 (1989); J. Scanlon and A. Frizzell, "Old Theories Don't Apply: Implications of Communications in Crises," *Disasters* 3(3), 315-19 (1979); R. H. Turner et al., *Waiting for Disaster*, University of California Press, Berkeley, Calif., 1986; A. F. Wallace, *An Exploratory Study of Individual and Community Behavior in an Extreme Situation*, National Research Council, National Academy of Sciences, Washington, D.C., 1956; K. P. Wilkinson and P. J. Ross, *Citizens' Responses to Warnings of Hurricane Camille*, Report 35, Social Science Research Center, Mississippi State University, State College, Miss., 1970; G. O. Windham et al., *Reactions to Storm Threat During Hurricane Eloise*, Report 51, Social Science Research Center, Mississippi State University, State College, Miss., 1977.

Three different viewpoints on warning are those of the detector, the manager, and the public.

The detector viewpoint is focused on the detection component of a warning system (monitoring, detection, data assessment and analysis, and prediction) and downplays other warning system components. It leads to a limited perception of a warning system: do good detection work, detect an impending emergency, and then tell people about it. It has acted in historical emergencies as a constraint on providing emergency managers with the kind of warning information they need. Emergency managers and the public need more than simply being informed about a hazard. Additional specific information is necessary, and it should be conveyed in appropriate ways. Joint planning between detectors and emergency managers has helped reduce this problem recently, but it is by no means solved.

The management viewpoint is that most likely to be held by emergency managers. This viewpoint is focused on the duties of emergency managers in a warning system (interpreting what those who have detected the hazard say, deciding to warn the public, determining the method and content of warnings, and monitoring public response). It leads to the following warning system focus: hear about the possible emergency from detectors, inform local emergency organizations, and then have them warn their public in whatever way they deem appropriate. This viewpoint has acted in historical emergencies to constrain providing the public with the type of warnings known to help people make good response decisions. The viewpoint is focused on getting the warning job done, and this facilitates warning the public. However, the manager viewpoint almost guarantees that different warning messages are presented to the public by different local leaders. It also can mean that warnings vary in sophistication about the possibilities for public response. This problem has been recently reduced for some hazards because of joint planning efforts between local, state, and federal emergency managers that include sharing knowledge about public response. Some of the problems posed by this viewpoint are not fully solved.

The third viewpoint about warning systems is the public view. This viewpoint reflects the public response component of warning systems. It leads to the following goals: define what is needed for good public response decisions; plan the system to achieve this objective; attempt to broaden the scientific and management viewpoints and remove the constraints they pose for warning system effectiveness; seek to hear, understand, believe, personalize, decide what to do; and then respond to warnings. Meeting these goals requires clear and information-rich warnings. This viewpoint demands more of the emergency management subsystem of a warning system than is typically provided. Some of the needs reflected in the public response viewpoint have begun to be incorporated into warning system preparedness for a few hazards, for example, at several nuclear power plants.

These three viewpoints exist in all warning systems because all systems involve detectors, managers, and members of the public. These perspectives must be broadened through interdisciplinary warning system preparedness. Only a few involved professionals have been able to broaden their warning system viewpoint beyond the one imposed by their organizational membership. Consequently, integrated warning systems remain the exception rather than the rule. All three warning system components must be recognized and integrated to create an effective system.

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3. BUILDING AND EVALUATING A WARNING SYSTEM

The future holds the potential for unimagined hazards for which warning systems may be useful, as technology advances (biotechnology is only one recent possibility), as more is learned about the natural world (poison gas at lake bottoms is only recently recognized as a significant natural threat), and as the strategies of political and social causes are stretched to new limits (urban terrorism against innocent civilians, although not a new idea, seems now to be a more frequent event). While all these hazards will continue to be varied and different, they may be more similar than dissimilar in relation to the need for warning systems. Warning systems for any low-probability catastrophic event share many organizational and human response components and building blocks. For example, detectors of a hazard must be linked to public warning disseminators, and citizens will respond to a warning on the basis of their situational risk perceptions regardless of hazard type. There are themes common to all warning systems; our common knowledge of these themes can serve as the blueprint for the construction of any warning system.

This chapter presents a common warning system blueprint, outlining the themes that are important in any effective warning system for a low-probability catastrophic event. The points we make are general, by design, and are applicable to all warning systems. The ways of adapting and implementing these general considerations for a particular hazard type are discussed in Sect. 6.

3.1 GOALS OF WARNING SYSTEMS

3.1.1 Alternative Goals and Audiences

The goal of any warning system is to alert and notify people of potential disaster to reduce death, injury, and loss of property. This obvious goal can be overlooked by persons involved in warning system preparedness. Warning systems typically cut across a variety of organizations. Membership in one organization with a limited warning role can constrain perceptions of warning system jobs. For example, hazard detecting organizations typically monitor the natural, technological, or civil environment to warn a political jurisdiction of an impending hazard. Such organizations may, therefore, view passing warning information to a governor as the end of their warning responsibility. A state bureaucracy which passes the information along to local government may view its warning role as completed when local officials are informed. The organizational and bureaucratic structures of society in the United States are such that the general goal of a warning system—to provide citizens at risk with information to maximize the odds that they will engage in some appropriate response to the risk—is too often defined as someone else's job. Moreover, in warnings, information needed by the public can be somewhat broader than that needed by organizations. Consequently, too often, actual public warnings can be inadequate while members of warning system organizations have done their jobs well.

Several specific goals might be sought to achieve the general goal of warning systems. The first is to get people at risk to listen to emergency information and to prepare them to respond with some sort of protective action. The second is to guide people to take what is considered to

be the best protective action. The third is to help people understand that their actions are part of an organized response to protect the community.

Warning systems involve a variety of organizational actors (Sect.2) and can include, for example, scientific monitoring organizations and federal, state, and local governments. Warning systems also involve a range of alternative target audiences—for example, the public at risk, the public not at risk, and special at-risk populations. A consequence of the innate structure of warning systems is that different goals (e.g., communicating risk information only to the next bureaucratic level versus telling the public) and different audiences (e.g., the public at risk versus the state bureaucracy) exist for different actors involved in warning systems. The factor that should not be overlooked by any warning system actor is the fundamental reason for the existence of the warning system: to inform the public at risk in a timely manner with the kind of information they need.

3.1.2 Alternative Protective Actions

The public has a limited number of strategies available to use in responding to a warning. One is to go about planned normal activities. The second is to seek more information. The third is to take some form of protective action. These alternatives are not mutually exclusive. Persons frequently engage in all or some of these in response to warnings. Protective actions themselves can also be divided into three alternatives. One is to take shelter in a structure or in protective clothing. A second is to move away from the area of likely impact. A third is to block or divert the impacts, as, for example, by sandbagging a river or using a protective mask in a toxic vapor cloud.

Public response to warnings differs for different hazards and depends on the threat and situation at the time of impact. At some point a policy decision must be made regarding what sort of protective action the public will be encouraged to take. As will be discussed in Sect.5, if guidance about appropriate responses is not provided, it should not be a surprise that different members of the public will respond in different ways. It is an inadequate warning strategy to simply pass risk information to the public without telling them what to do for their safety.

3.1.3 Myths That Confuse Goals

In designing and implementing a warning system, warning system actors and decision makers should not fall prey to myths that have historically undermined public warnings. To summarize, the fallacies of these myths are as follows.

First, the public simply does not panic in response to warnings of impending disasters. Hollywood and Tokyo screenplays are probable culprits in the propagation of the panic myth. Research documents that panic occurs only in situations in which there is closed physical space, in which there is an immediate and clear threat of death, and in which escape routes will not accommodate all those in danger in the minutes before death comes to those left behind. Thus, panic does not follow a warning except in very rare circumstances.

Second, the public rarely if ever gets too much emergency information in an official warning. It is true that people do not remember all the information contained in a warning if they hear it only once; therefore, detailed messages should be repeated in an emergency. Emergency warnings are simply not subject to the 30-s rule known to operate in Madison Avenue attempts to sell toothpaste and deodorant soap. People are information hungry in a warning situation.

They should be provided with all the information they need, and this information can be part of warning messages.

Third, the effectiveness of people's responses to warnings is not diminished by what has come to be labelled the "cry wolf" syndrome, if they have been informed of the reasons for previous "misses." Obviously, there would be a negative effect on subsequent public response if false alarms occurred frequently, if no attempt was made to explain why there were false alarms, and if the cost of response is high. Yet, false alarms, if explained, may actually enhance the public's awareness of hazard and its ability to process risk information in subsequent warning events. False alarms are better viewed as opportunities for conveying information than as problems.

Fourth, people at risk want information from a variety of sources and not from a single spokesperson. Multiple sources help people confirm the warning information and the situation, and reinforce belief in the content of the warning message. This does not mean that multiple and different warning messages from different spokespersons are desirable. The objective could be achieved in one of two ways. Different spokespersons could all deliver the same message, or a panel of spokespersons could deliver a warning a number of times.

Fifth, most people simply do not respond with protective actions to warning messages as soon as they hear their first warning. Most people seek more information about the impending risk, and appropriate responses from people they know and from other information sources. People call friends, relatives, and neighbors to find out what they plan to do. People also turn on radio and television to get more information.

Sixth, most people will not blindly follow instructions in a warning message unless the basis for the instruction is given in the message and that basis makes common sense. If instructions in an official warning do not make sense, people typically will behave according to other information sources that do supply sensible instructions.

Last, people do not remember what the sounding of various siren signal patterns means, but they may try to find out the reason for the siren if it continues to sound or is repeated. Sirens are best viewed and used as an alert for the public to seek out other emergency information, rather than as a signal that should elicit adaptive and protective actions from the public. An exception may be the frequent use of siren drills through which response becomes automatic. This use is largely inappropriate for the general public, but it may be useful in work settings or in special situations that can be supported by an intensive education program.

Fear of public panic in response to warnings, the idea that a warning must be so short as to rob the public of needed information, fear of false alarms based on the "cry wolf" syndrome, and the other myths just reviewed have often acted as constraints preventing warning systems from achieving their general goal of maximizing good public response decisions. There must be a continuing effort to convince planners to abandon these deep-seated myths.

3.2 LINKS WITH HAZARD DETECTORS

A warning system cannot function if appropriate emergency officials do not receive timely information about risk. The failure of officials to receive information in a warning sequence is a documented cause of many warning system failures (see Sect.4). Emergency officers cannot always assume that they will receive this information reliably. A warning plan must take a proactive approach on establishing links between hazard detectors and emergency

managers. Emergency planners should first identify those who detect each relevant hazard for their jurisdiction (see Fig.3.1). As part of this identification, planners should meet with the group detecting the hazard and learn the process by which they collect, process, and report information.

The next step is to develop the appropriate hardware link (and a backup link) to ensure that a physical means for communication exists. Nondedicated phone lines are not a reliable primary or backup link. Agreements on when the detector can communicate information to officials should be established and documented. Finally, an understanding of how the organization will maintain relationships in an emerging warning situation should be established.

Such prior arrangements will help to develop better working relationships in an emergency. They will also facilitate open and timely communication between these two parts of the warning system network.

3.3 INTERPRETING HAZARDS COMMUNICATIONS

3.3.1 Preparing for Interpreting Scientific Information

Emergency managers in a warning system must become technically and scientifically informed in order to be able to make warning decisions on the basis of received scientific and technical information. It is also part of the detector's responsibility to communicate information in ways which will make it understandable to emergency managers. Managers must gain a fundamental understanding of the risk or hazard systems with which they are dealing in the warning process. Managers do not need to become technical and scientific experts themselves; however, they must develop a knowledge base adequate for understanding when communicating with experts in a warning context. It will probably be the warning manager's responsibility to further translate technical or scientific information relayed to him by detectors into a format and language that the public can understand and to translate risk information into hazard terms and then into recommended public protection actions.

In many emergencies, this learning takes place rapidly during the first phase of the warning process. When approached in this fashion, learning has varying degrees of success. An alternative to situational learning is planning. Under planned learning, one can envision a range of alternative risk scenarios, seek to specify the circumstances in which such scenarios are possible and develop an understanding of what sort of risk exists for the public in reference to each scenario.

3.3.2 Preparing for Interpreting Nonscientific Information

Emergency managers who play a warning systems role must also be prepared to receive information from detectors about risk regarding hazards such as civil crisis. This information must be translated into public risk information that can provide a basis for recommended public protective actions. This translation will likely be less time consuming if it is facilitated by knowledge and planning.

PLANNING TASK	HAZARD		
	VOLCANO	FLOODS	WATER TREATMENT PLANT
WHO DETECTS	Volcano observatory	National Weather Service	Plant shift supervisor
COMMUNICATION LINKS FROM DETECTOR TO EMERGENCY MANAGER	Dedicated phone or radio	Teletype or commercial phone	Alarm or radio
INITIATION OF NOTIFICATION	When a prediction is made	When flash flood alert is issued	When a release is detected
MAINTENANCE OF COMMUNICATIONS IN AN EMERGENCY	Send representative to volcano to observe	Establish two-way radio contact	Set up computer link via modem

Fig. 3.1. Examples of detection-management linkages.

3.3.3 Dealing with Probability, Uncertainty, and Disagreement

The behavior of many hazardous systems (geological, climatological, technological, and national security) for which warnings are designed is based on probability. When certain conditions are present, a hazard system may pose a threat only part of the time. This poses problems for warning officials because it is difficult to use probability concepts in warnings. People tend to view risk in more absolute terms: will a hazardous event occur or not. This could be changing, in part because of recent efforts to educate the public about probabilities. For example, NWS uses probabilities in many of its warnings. Scientists couch their predictions in probabilistic terms, but warning officials need to make a yes or no decision to warn. They do not have the luxury of repeating the scientific information to the public. They have to convey with confidence the need to take protective actions in an uncertain situation.

Another problem for warning officials is dealing with conflicting information, opinions, and interpretations. It is highly likely that such disagreements will reach the public through the media, because the media tend to seek out and publicize both sides of most stories.

A reasonable philosophy for emergency managers to consider in dealing with uncertainty and conflict in risk information is one of prudence. If in doubt, one could opt for the warning strategy that will err on the side of protecting the public. Such action is perhaps most prudent if performed on the basis of information from scientists or risk detectors with formal responsibilities to gather such data. In such cases, the public can be brought to better understand uncertainty, and the basis for cautious decisions, in the public interest. The bottom line is that emergency managers must recognize that most risk situations are probabilistic. Planning should address under what circumstances warnings

should be issued to the public and when probabilities are so low as to be ignored from a public warning viewpoint.

3.4 DECIDING TO WARN

3.4.1 What the Decisions Are

Four basic decisions face emergency managers confronted with risk information from detectors as they ponder communicating warnings to the public. These are whether to warn the public, when to issue the warning, who and where to warn, and how to warn.

3.4.1.1 Whether to Warn

There are many circumstances in which there is no alternative to a public warning. Some examples are the sighting of a funnel cloud moving on a path toward a populated area or the occurrence of a certain category of accident at a nuclear power plant, in which case a public warning is required by law. Cases like these are more rare than common. In most events, the probability of actual impact is less than certain, and the legal system has not clearly determined when warnings will and will not be issued. In many of these cases emergency managers have determined that public warnings were not needed because of the low-probability of impact. They wish to avoid public "panic," the economic costs of "unwarranted" warning and public response, or the loss of credibility resulting from a false alarm. While these are recurring concerns, they rarely prove to be valid. The public would rather be safe than sorry. People tolerate false alarms if there is a valid scientific rationale for the warning and the "miss." For example, the public has been tolerant of hurricane warnings, for which there is an evacuation-warning false alarm rate of 70%. People subject to this hazard are willing to evacuate needlessly 70% of the time to ensure that they will avoid staying when evacuation is needed. The bottom line is, when in doubt, warn. The consequences of being wrong are more severe if a disaster occurs when there has been no public warning than if a disaster does not occur after warning. In addition, even if an official warning is not issued, unofficial ones are likely to be made as information about the risk becomes available to the press and the public.

We noted in the first chapter of this report that public warning systems are capable of disseminating safety as well as risk information. Risk information exists on a continuum that ranges from "background," with extremely low probabilities of risk, to risk with a 100% probability of materializing. Most of the events that precipitate the use of a warning system fall somewhere between background probability and 100%. The question of whether to warn or not is best cast not as whether the public needs to be told about risk or not, but instead as at what point should emergency managers recommend through public warnings that people act as if impact will occur and, therefore, engage in protective actions. The answer to this question is rarely simple or straightforward. The decision must be made as events occur, and it would be better as the consequence of planning rather than being influenced by unpredictable pressures operating in actual emergencies.

3.4.1.2 When to Warn

Emergency officials have sometimes delayed issuing public warnings in order to get more information and increase their confidence that they will issue a "correct" warning. There is a belief that people will not respond if the lead time to act is too long, yet the ultimate danger of delay is issuing a warning when it is too late for people to take protective action. Ideally, a warning should be issued early and its content geared to the uncertainty and likelihood of the event. The warning then can be revised to reflect the changing circumstances. Early and open disclosure will prevent officials from being "scooped" by unofficial sources such as the media or being accused of a cover-up. Failure to disclose information can undermine the credibility of those issuing information to the public through the emergency warning system.

3.4.1.3 Who and Where to Warn

The next major decision concerns which geographical area to warn given the projected impact of the disaster. This decision also includes determining which if any areas should be informed that they are not at risk, and whether different areas are at different risk and should receive different warnings. These decisions are limited by available data and knowledge about how to use the data that are available. The precision with which these decisions can be made is determined by the particular hazard, the ability to measure risk and hazard, and the analytical tools available to the decision maker. It is desirable to have established knowledge about impact before the time when public emergency warnings are being considered. Such knowledge should not be given inflexible boundaries. For example, the Chernobyl nuclear power plant accident illustrated that a planned for 10-mile risk zone did not take into account radiological hazards at 50 or 100 miles. Other events that are more geographically random, such as terrorism or transportation spills of hazardous materials, need a highly flexible warning dissemination system. The lessons gained from some historical events also illustrate that caution is also prudent. It is better to warn a large area than to have to react quickly as the impacts spread into unwarned areas.

3.4.1.4 How to Warn

The final decision to be faced is the decision about how to disseminate the warning to the public. The decision includes specifying the source of the warning, the channel of communication, the message content, the frequency with which the warning is given, and whether different audiences within the same areas require different warnings; for example, warning may be given in several languages. These topics are the subject of the latter part of this chapter.

3.4.2 Who Decides to Warn

It is important that a warning plan specify who will decide to issue a warning before a decision is needed. One problem that can occur is competition for warning authority, which can delay or prevent a good decision. Where possible, decisions should rest with people with normal day-to-day decision authority. This avoids confusion or conflict even when the decision is specified.

Either an individual or a group can have warning decision authority. If this authority rests with an individual, a back-up decision structure should be specified in case that individual is unavailable, and if decision authority rests with a group, the membership and convening mechanism should be established as well as backup procedures should the group be unable to convene. Who decides may be determined by legal mandate. In some states, only the governor can legally issue a warning; in others, the person in authority may be a county sheriff or a local mayor. In any case, planners should ensure that a prompt decision can be made if the situation calls for a rapid warning.

3.4.3 Decision-Making Processes

It is also desirable to specify in plans how the warning decision will be made in the emergency situation. This involves establishing the broad criteria on which to make a decision and indicating how those criteria should be used. Rigid decision-making frameworks should be avoided. Human judgment is still an important and necessary part of decision making even with today's advanced technology.

Analytical models and decision criteria are helpful to making good decisions, but these tools cannot make the decision. For example, one warning decision system we reviewed involved a complex model in which data were entered and the system made a yes or no warning decision. But as the final step of the process the decision maker could override the model and go ahead with the warning anyway. Decision models may be of greater use in deciding when and where to warn than in actually deciding whether to warn. The exception would be for extremely fast-moving events in which a warning must be automatically triggered to provide sufficient time for the public to take protective actions.

3.5 WRITING THE WARNING MESSAGE

One of the clearest and most consistent conclusions of social science research is that the warning message itself is one of the most important factors in determining the effectiveness of a warning system. In large part, it is the content and style of the actual warning message that shapes the extent to which an endangered public engages in protective actions.

In the following section, we review the elements of both message style and content that should be considered in writing a public warning. Before proceeding, however, let us correct the notion that public warning messages must be short or else the endangered public will become confused or lose interest in the subject. The public does have a short attention span. But major emergencies like tsunamis, dam failures, and nuclear power plant accidents are unique in terms of how willing a public is to listen to information. Emergency warnings of impending catastrophes convert an information-adverse public (you have only 30 seconds to convince me to buy your product) into a public that is information hungry (why are we at risk, do you really mean me, how long do I have, what is it you think I should do, and so on). Warning messages that "keep it short" are inappropriate in public emergencies because short messages set a diverse at-risk public on an information scavenger hunt to fill the information voids left by the short message. Such brief messages can be dangerous since they can lead people to consult friends, neighbors, relatives, superstitions, biases, and a raft of other "information providers" to fill the void. These other sources may provide inaccurate information (it never floods here, lightning never strikes in the same place twice and we had ours last year, all nuclear power accidents release radiation as

happened at Chernobyl) and create rumors. Subsequently, poor public response decisions or lack of protective actions can result. The sections which follow address the style and content of public emergency messages appropriate for inclusion in plans for warnings.

3.5.1 The Warning Content

Five topics are important to consider in assembling the content of a public warning message. These topics are hazard or risk, guidance, location, time, and source (Fig.3.2).

3.5.1.1 Hazard

A warning message must provide the public with information about the impending hazard by describing the event that may occur and how it poses a danger to people. It is insufficient, for example, for a warning to simply state that a dam may break. This warning must also describe the height and speed of impact of the floodwaters that will ensue, and the size and location of the areas that could be affected. A warning for a nuclear power plant accident might indicate that the radiation will filter into the air like a cloud and then travel with the wind while becoming less and less concentrated.

These examples are not meant as prototype descriptions for dam failure and nuclear power plant radiation releases. They simply illustrate that warnings should be specific about the character of the hazards involved. A warning could describe "a wall of water 20 feet high moving at 40 miles per hour," "an explosion hotter than the inside of the sun covering half of the county," "or a seismic shake severe enough to bring down half the unreinforced brick buildings in the city." If a hazard is well described, people are better able to understand the logic of protective actions, (e.g., close the windows in the house because the risk is in the air; get out of brick buildings because they may fall down).

Thus, hazards should be described with sufficient detail so that all members of the public understand the character of the disaster agent from which they are to protect themselves. Informing the public about the physical characteristics of the hazard will reduce the number of people in an endangered public who misperceive the hazard and then make poor response decisions because of those misperceptions. The hazard aspect of warning message content provides the public with a rationale for subsequent behavior.

3.5.1.2 Guidance

Public warning messages must also include guidance about what people should do to maximize their safety in the face of impending disaster. It cannot be assumed that members of the public will know what constitutes an appropriate protective action. The protective action must be described. This point may seem obvious, but it is not. For example, warnings must do more than tell people that they should "get to high ground." High ground for some may be the low ground for others. High ground should be defined—for example, "ground higher than the top of City Hall," or specify areas to which people should evacuate.

MESSAGE STYLE	MESSAGE CONTENT				
	HAZARD	LOCATION	GUIDANCE	TIME	SOURCES
SPECIFICITY					
CONSISTENCY					
ACCURACY					
CERTAINTY					
CLARITY					

Fig. 3.2. The style and content of a warning message.

3.5.1.3 Location

A warning message must also describe the location of risk because of the impending hazard. The hazard factor first described and this location factor are closely linked. Detailing the location of risk is best done in ways readily understood by the public. For example, a flash flood warning could say: "The area of town that will flood will be between Second and Fifth Streets, from Elm Avenue to Magnolia Boulevard." If there is reason to be concerned that people who are safe could think that they are unsafe, then the warning should address them—for example, "People who live in other parts of the city will not experience flooding"—but the warning should then explain why they are safe. This is usually necessary because a wider audience than those at risk will hear the warning message.

3.5.1.4 Time

Public warnings must also address the "when" aspect of response. The public at risk needs information about how much time is available for them to engage in protective actions before impact, or how much time there is before they should initiate protective actions. For example, "The tsunamis would not strike before 10 p.m. this evening, and you should be on the northern side of U.S. Highway 72 by 9:45 p.m. to be on the safe side."

3.5.1.5 Source

The final important dimension of warning content is the source of the warning. The source of the warning should be identified in the message. Warnings are most believable if they come from a mixed set of persons. For example, "The mayor and the head of civil defense have just conferred with scientists from our local university and the National Weather Service as well as with the head of our local Red Cross chapter, and we now wish to warn you that. . . ."

3.5.2 The Warning Style

The five aspects of warning content can be cross-classified against the varied stylistic aspects of a warning message (Fig.3.2). The stylistic aspects are specificity, consistency, accuracy, certainty, and clarity. A warning message could readily be evaluated by viewing the specificity of the message regarding location, guidance, hazard and time; the consistency of the message regarding these same content factors; and so on. The sections which follow describe the quality of the five stylistic aspects of the most effective public warnings.

3.5.2.1 Specificity

A good warning message is specific about the area at risk, what people should do, the character of the hazard, how much time people have to engage in protective actions, and the source of the message. There are many occasions when specificity on all these items cannot be high. Something may be unknown or known imprecisely. On these occasions, the warning message itself need not be nonspecific. For example, "We do not know nor can it be known which buildings in the city will be safe and which will not be safe when the earthquake strikes, but we do know that most people will be safer if they go home now."

3.5.2.2 Consistency

A warning message must also be consistent, both within itself as well as across different messages. Inconsistencies exist within a message for a variety of reasons and in different ways. For example, it is inconsistent to tell a public to evacuate but that their children will be kept in neighborhood schools. In most emergencies there are numerous inconsistencies across different warnings as more is learned about the impending event and updates are issued. For example, inconsistencies can appear as new information reveals that the hazard has decreased or increased, the number of people at risk has become larger or smaller, and so on. Consistency can be rendered across messages in circumstances such as these by simply referencing and repeating what was last said, what has changed, and why.

3.5.2.3 Certainty

A message should be stated with certainty even in circumstances in which there is ambiguity associated with the hazard's impact. For example, "There is no way for us to know if there really is a bomb in the skyscraper, or that it will actually go off at 3p.m. if there is, but we have decided to recommend that the building be evacuated now, and that we will act as if the bomb threat is a real one." Certainty in warning messages extend beyond message content to include the tone with which it is delivered to the public. The warning should be spoken by the person delivering it as if he or she believes or is certain about what is being said.

3.5.2.4 Clarity

Warnings must be worded in simple language that can be understood. For example, "a possible transient excursion of the reactor resulting in a sudden relocation of the core materials outside the containment vessel" might better be stated as "some radiation may escape from a hole in the nuclear reactor."

3.5.2.5 Accuracy

The last important stylistic attribute is accuracy. A warning message must contain timely, accurate, and complete information. If people learn or suspect that they are not receiving the whole truth, they may well not believe the message, or they may consider its sources to be noncredible. Accuracy is enhanced simply by being fully open and honest with the public regarding a hazard. In addition, accuracy is important in parts of the warning that may be viewed by officials as being trivial. For example, calling Broad Street "Board" Street by mistake may send a signal to the public that other essential information is also incorrect, even though they can correct the error on the basis of personal knowledge.

3.6 DISSEMINATING THE MESSAGE

3.6.1 Warning System Communication Channels

Warnings can be issued to the public in a variety of ways. They can be conveyed by voice, electronic signals, or printed medium. Voices can be direct or broadcast over loudspeakers, public address systems, telephone, radio, or television. Signals include sirens, alarms, whistles, signs, and lights. Leaflets or video can be used to distribute graphic information and printed messages. In this section we review briefly the technology of each warning channel and discuss the strengths and weaknesses of each.

3.6.1.1 Personal Notification

Personal notification involves using emergency personnel to go door-to-door or to groups of people to deliver a personal warning message. This type of warning mechanism can be used in sparsely populated areas, in areas with a large seasonal or diurnal population (such as recreation areas), in areas not covered by electronic warning capabilities, and in areas with adequate numbers of emergency personnel.

The chief advantage of personal contact is that people are more willing to respond to a warning delivered personally because they are more likely to believe that a danger exists. However, this method is time-consuming and may require the commitment of many vehicles and persons. To support the implementation of this method, emergency personnel should develop a plan for systematically traversing the threatened area and should issue the warning, beginning with the highest risk zone and proceeding to those of lower risk. A trial run is useful for establishing the warning time needed to notify the population at risk and for establishing a rate for different types of areas.

3.6.1.2 Loudspeakers and PA Systems

It is feasible to use existing public address (PA) systems to notify people in areas which are covered by such systems. Schools, hospitals, prisons, nursing homes, sports arenas, theaters, or shopping centers often have PA systems. In addition, portable loudspeakers can be used from vehicles to warn nearby populations; often these are used in conjunction with personal notification procedures. Existing PA systems supplement other warning system communication networks. They are useful in reaching small segments of the population in confined settings. To be effective, PA systems need a good communications link to the operators so that messages can be disseminated quickly and accurately. Portable loudspeakers increase the speed of warning populations lacking other means to receive the warning. They are particularly useful during night-time hours when many people are asleep. Their chief disadvantages are that it is often difficult for people to hear a warning broadcast from a moving vehicle, that sometimes people only hear part of the message, and that it is difficult for people to confirm the warning.

3.6.1.3 Radio

Radio is a major channel for disseminating warning information because it can quickly reach a large number of people during nonsleeping hours. Certain EBS radio stations have been

designated as part of the NAWAS system. These stations usually have arrangements with local civil defense offices or other government agencies to broadcast emergency warnings for most hazards. In most situations, other radio stations broadcast warnings as well. The use of radio as a warning channel will continue to be a major practice in emergencies. Often plans for notification and the use of standardized messages accelerate the speed at which a warning can be issued over the radio. One disadvantage of the radio is that the broad area often covered by broadcasts may include areas not at risk. Second, radio messages exclude the use of graphic materials. Third, radio reaches only a small portion of the population during late night-time hours.

3.6.1.4 Tone Alert Radio

The tone alert radio is a specialized warning device that can be remotely activated. These radios operate on a standby condition and provide a warning signal; some types can subsequently broadcast a verbal warning message. Upon receipt of a code, the radio emits a tone and broadcasts a prerecorded or read message. The code and message are broadcast from a radio transmitter which typically has a range of 40 miles. The radio receivers operate on normal electric power; some have battery back-ups.

One tone alert system is NOAA Weather Radio. This system covers a major portion of the population within the country. Its chief function is to provide continuous weather forecasts. NWS can activate radio receivers to issue warnings regarding severe weather. This system can be used to issue warnings for other hazards such as nuclear attack or nuclear power accidents by pre-arrangement with the NWS. The advantages of the tone-alert system include a quick dissemination time, the combination of an alerting signal with specialized messages, and around-the-clock availability. Disadvantages include maintenance problems, availability during power failures, limited broadcast range, and the difficulty of outdoor use. The radio receivers are relatively inexpensive, costing less than \$50.

3.6.1.5 Television

Warnings are also broadcast over commercial television. This can be done by interrupting normal programming or by displaying scrolled text on the bottom of the screen. Television reaches a large number of people, particularly in the evening hours. Like radio, it is a poor channel during sleeping hours. Television is a particularly good channel for warnings about slowly developing events. It is likely to take longer to issue a warning over television stations except where prewritten scrolled messages are used. One major advantage of television is the ability to use graphic information such as maps or diagrams in the warning.

3.6.1.6 Cable Override

The existence of cable television in many areas means that local commercial stations may reach less of the public than once was the case. As a result, systems have been developed to issue scrolled or broadcast messages over all cable channels. Thus, a person in Cheyenne, Wyoming, watching a Chicago station or a movie channel could still receive a tornado warning. Usually the override systems are operated by local civil defense offices in coordination with a

cable television station. This requires pre-arranged agreements on the use of such a system. The advantages and disadvantages of normal television apply.

3.6.1.7 Telephone Automatic Dialers

Switching and automatic dialing equipment that is currently available has the potential to reach a large number of people in a relatively short time frame. In most cases, current technology could allow a simultaneous call to about 20 to 30% of a local phone company's customers using the local system's resources and to a higher percentage by routing calls through distant switching stations. These systems make use of existing phone networks. Other systems can be specifically designed to issue emergency warnings. Most of the modifications and special equipment are installed at the phone company. These systems play prerecorded messages which can be updated fairly quickly to provide timely information. Advanced systems can automatically hang up phones in use or block out all incoming calls. It is also feasible to have them use a special ring that would act as an alerting function. They can also be combined with the use of telephone hotlines to provide specialized information. Automatic dialing systems are expensive and for this reason limited in their use. Further, without modifications of the system they can still serve only a fraction of local area phones at one time. Other problems exist. People are not always near a phone to receive a message, and busy phones would prevent warning if less expensive systems without the automatic hang up feature are used. Deregulation of the phone industry may constrain the use of these systems due to the segmented market. Because of these problems, automatic telephone systems are currently used chiefly for organizations but not for the public; for example, they are used to notify emergency response personnel and to warn institutional facilities such as hospitals at risk during nuclear power plant accidents.

3.6.1.8 Sirens and Alarms

The technology of siren and alarm systems is such that an audible signal could be provided to most populations at risk, although it might be expensive to implement the technology. These types of warning devices are designed to provide rapid alert to the threatened population. While a few types of sirens have public address capabilities as well, most only sound a noise. Siren systems are limited in their use by the lack of instructional messages. At best they alert people to seek further information unless there has been an intensive program of public education used to instruct people what to do when the signal sounds. This is possible only in situations when the same response would be desired every time a warning is issued.

Multiple signals, such as a wavering signal versus short blasts, are rarely differentiated by the public. Consequently, reliance on different signals is on fairly weak grounds. Other problems that constrain the use of sirens and alarms are false alarms because of technical failures, equipment failures in emergencies, maintenance problems, coverage problems (particularly in adverse weather), difficulties in propagating sounds into buildings, and sometimes public indifference to sirens in largely urban areas. Siren systems are a main component of many warning systems in use today despite all these problems.

3.6.1.9 Signs

Permanent warning signs are sometimes used to directly communicate to the public in remote hazardous areas. These signs often instruct people about how to recognize the onset of a hazard and what to do if one occurs. Signs can be used to supplement more effective warning devices if they are in good locations for viewing and if they are visible at the time an emergency occurs. In addition, signs may serve as a valuable educational device; people who see them frequently may learn what to do in an emergency without needing a specialized warning. Problems with signs include their need for periodic maintenance and replacement and identifying their proper locations.

3.6.1.10 Aircraft

In special cases, airplanes and helicopters can be used as part of the warning process. Low-flying aircraft can carry sirens or bullhorns to provide an alert or a warning message. In addition, they could drop prepared leaflets containing a warning message. This type of warning channel is useful in reaching remote populations or populations that cannot be reached through normal communication channels. Disadvantages include access to aircraft, maintenance, cost and the risk of accident in difficult flight terrain. A further problem is obtaining sound systems that can broadcast messages audible over the noise of the aircraft itself.

3.6.2 Selecting the Channel

The choice of a channel or set of channels to be used depends on the hazard at issue, as well as the characteristics of the population at risk. The use of a matrix filled with channel types for a particular area (Fig.3.3) provides information that could help ensure that special subpopulations are targeted with appropriate channels of communication for different hazards. Such a planning technique approach could ensure that warnings can reach all those at risk for each potential hazardous situation. Whenever feasible, the warning system should use multiple channels to ensure overlap and comprehensive coverage. Channels also need to be selected on the basis of the amount of information each is capable of conveying and the amount of information needed to describe the hazard and appropriate response.

POPULATION SUBGROUP	HAZARD		
	VOLCANO	FLOOD	CHEMICAL PLANT
PERMANENT Urban residential Rural residential Apartments	Media/Emergency Broadcast System	Door to door	Sirens
INSTITUTIONAL Hospitals Schools Nursing homes	Commercial telephone	Tone alert radio	Tone alert radio
TRANSIENT Highway Sports facility Parks	Signs	Barricades	Loudspeakers

Fig. 3.3. A guide for selecting warning channels.

3.6.3 Frequency of Dissemination

There is no magic formula for specifying how frequently a warning message should be repeated, but some guidelines can be established on the basis of knowledge about how the public processes warning information. In part, dissemination frequency is geared to the dynamics of the emerging risk and its severity, as well as being influenced by increased or changed knowledge about it. Frequency is best dictated by the needs of the public at risk.

The major lesson on this point, as research has shown, is that it is difficult provide people at risk with too many warnings. People want updates of information even when there is little change in the content. In protracted emergencies, however, there is a point of diminishing returns after which constant delivery of no new information may be counterproductive. The frequency of warnings should diminish after the initial warning period, but warning officials should be ready to increase the frequency of warnings if the risk changes.

There are a number of potential advantages of frequently recurring warning messages. Frequently recurring warnings (e.g., "This message will be repeated over this same station every fifteen minutes, unless new information updates are available") focus people on official warnings, reduce rumors, and increase public confidence in the validity of the warnings.

3.7 MONITORING RESPONSE

The chief reason for monitoring public response to a warning is to determine whether the warning system is guiding behavior in a manner consistent with the potential hazard and disaster risks. If people are engaging in actions that place them at greater risk, the warning may have been poor. If the warning is not effective, adjustments in the warning process may be needed. These adjustments may include changing the contents, tone and clarity of the message, the frequency of dissemination, the channel of dissemination, the source of the information, or other basic facets of the warning process.

3.7.1 Methods of Monitoring Response

There are several ways to monitor public response to disaster warnings. No one method is necessarily better than another, and a mix of methods could be used in a particular event. We briefly describe each of the methods below.

3.7.1.1 Communication Lines to the Field

One way to gain feedback about response is to communicate with emergency workers such as law enforcement officers on the periphery of the targeted warning area. This type of communication can only provide qualitative assessments of warning response. For example, if the advice is to take shelter and people are observed on the streets, it is apparent that not everyone is following the advice of the warning. One role of an emergency operations center (EOC) is to organize qualitative field observations into a general picture to determine if revised warnings are needed. In most disaster settings this type of reporting is done on an adhoc basis. However, some situations may warrant more carefully planned feedback. In such cases, it may be desirable to establish reporting requirements for some field personnel or a set of questions to ask while communicating with field personnel.

3.7.1.2 Systematic Observation

In some situations, it may be desirable to have personnel assigned to observe and perhaps even measure human response systematically. This can be done in several ways. For a large-scale evacuation, traffic guides might estimate the number of vehicles passing by on central routes. Shelter workers might regularly report the number of people arriving at shelters. Such observation plans can be tailored to the specific risk situation.

3.7.3.1 Unobtrusive Measures

Unobtrusive indicators of public warning response may also be feasible. One obvious indicator is a real-time traffic counter that measures vehicle flows from an area. These counters can be used to measure evacuation from risk areas provided the monitors are in the right locations. Other possibilities include monitoring utility use rates such as water or electricity consumption; this approach, however, is hypothetical and has not been tested.

3.7.2 Establishing a Monitoring System

A public monitoring system is an important part of a comprehensive warning plan even though it may not seem relevant before a disaster. A number of postdisaster audits show that if officials had known what was happening, a revised message or a different warning strategy could have produced a more effective response or, in some cases, saved lives. Yet, few emergency plans have adopted the concept of a monitoring system. Monitoring takes place informally in some emergencies, but is rarely labeled or formalized.

A first step in establishing monitoring capabilities is to review how information will be fed into the EOC during an emergency and assess whether this method is adequate to provide information on public response. If the information feedback system is adequate, planners should structure the nature of the reporting to be done and indicate by whom it will be done; they should also make sure that a back-up means of communication exists. If the existing communications are inadequate, provisions for adding personnel in the field to provide reports may be necessary.

Potential problem areas—such as a narrow bridge on a hurricane evacuation route, major freeways in an urban area, shelters in a densely populated neighborhood, or institutional facilities housing special populations—may warrant a designated and dedicated feedback mechanism.

3.8 TESTING WARNING SYSTEMS

As we have seen, warning systems are not simple systems. They cut across a variety of types of organizations— scientific organizations, government bureaucracies at all levels, private corporations, and so on—and involve people from a wide range of backgrounds (e.g., scientists, elected officials, bureaucrats, military personnel, and the public). Warning systems are composed of links and communication between all involved organizations. Some of these linkages are routinely used, while others are unique or scheduled for use only when the warning system is implemented. Obviously, warning systems do not have a life of their own; they are artificial organizational arrangements that may be rarely used, except for warning systems for frequently

occurring events. Infrequently used systems must conduct tests and exercises to discover and correct flaws that would almost certainly otherwise arise during an actual emergency.

The most apparently realistic way of testing a warning system is through the use of full-system exercises. In such exercises, all facets of the system can be drilled from initial detection up to but not including the dissemination of public warnings. Public warnings are excluded because involving the public in exercise response is not necessary for discovering and correcting flaws in the system except in the testing of the warning communication-channel hardware (e.g., a siren). However, full-system exercises limit the number of things that can be carefully evaluated. Partial-system exercises can sometimes be preferable since they can focus on the most important or questionable parts of the warning system.

3.9 POSTSCRIPT

In this section we have presented what we feel are basic planning and evaluation warning system concepts, based on social science research findings concerning the organizational and public response aspects of such systems. The outline of the section constitutes a checklist of concepts to be addressed in planning and evaluating any public warning system. We recognize that the way these concepts are implemented may vary across hazard types, or across different jurisdictions with different local political realities, but the concepts discussed here are the building blocks of an ideal warning system.

4. ORGANIZATIONAL ASPECTS OF WARNING SYSTEMS

This section focuses on the detection and emergency management components of warning systems. These two components both typically involve organizations, relationships between organizations, and the behavior of individuals in those organizations. It is also possible for people who are not organizational members to participate in these two components of a warning system. Nonmember participation in these warning system components was presented in Sect.2. Public response, the third component of warning systems, is addressed in Sect.5.

In the first part of this section, the warning dilemmas and uncertainties facing technicians, scientists and emergency managers are reviewed and discussed. This discussion of organizational warning problems is followed by a section summarizing the factors that help to mitigate these dilemmas and enhance warning system effectiveness. This discussion of solutions is followed by the chapter conclusion with a review of principles that are important for developing effective warning systems.

4.1 ORGANIZATIONAL DILEMMAS

4.1.1 Interpretation Dilemmas

Information about an impending hazardous event must work its way from event detection to prudent public warning decision. Along the way, this information is subject to the interpretations of those who process it and pass it along to others. These interpretations can facilitate the warning process if they are sound. They also can raise uncertainties in the system and give rise to subsequent bad decisions. Interpretation uncertainties concern the recognition of the event, the recognition that the event is hazardous, a definition of the magnitude of the hazard, a recognition of the warning system's role, a recognition of relevant information, and a recognition of authority. Such uncertainties can be reduced with systematic planning and decision methodologies (Lindell et al. 1985), but it is difficult to imagine a time when all uncertainties could be eliminated.

4.1.1.1 Recognition of Event

The ability to recognize the presence of an impending event is determined by the degree to which an indicator of the potential threat can be detected and the conclusion reached that a threat exists. For example, observation of a particular cloud formation may suggest rain to some, a tornado threat to a few, and merely a cloudy day to others. Both "trained" observers and members of the public vary in their ability to recognize a potential threat. The variable abilities of people to recognize threat has delayed some warnings, thereby reducing the time available for public response. For instance, in several recent dam failures, the company responsible for managing the reservoir failed to understand that the dams were unsafe. The inability to link runoff conditions with dam failure precluded early warnings. This was a problem to a limited extent in the Lawn Lake dam failure (Graham and Brown 1983) and was a major contributing factor in the Buffalo Creek dam disaster (Erikson 1976). A procedure in place that clearly specifies how to monitor for the presence of events can help reduce uncertainty in such circumstances.

4.1.1.2 Recognition of Hazard

Variation in the ability to define the level of threat, once the presence of an event has been recognized, is a second uncertainty that has constrained effective and timely hazard recognition. Once the physical properties of an impending event are recognized, uncertainties can exist in reference to event impacts. For example, an impending flood could affect a large part of town or only a small segment of it; a hurricane could produce hazardous winds for 30 miles inland or only for 3 miles; a terrorist threat may or may not actually result in an attack. The inability of managers to recognize the extent of public hazard associated with an impending event has been the cause of overestimating and underestimating the seriousness of impending emergencies. In some cases, this uncertainty has led to less effective and poorly timed warning decisions. Implicit in the recognition of hazard is the trade-off between false alerts, true positives, and warning lead time. As the sensitivity of a warning system increases, the number of correct definitions of hazards will also increase (Pate-Cornell 1983, 1986).

The warning and evacuation of 225,000 people in Mississauga, Canada, following a train derailment was effective only because the ensuing fire caused hazardous fumes to rise above nearby residents. Initially, warning decisions were hampered by officials' inability to determine the hazardous materials on the train. When the manifest was located, officials were uncertain as to whether or not it was accurate. If it had not been for the fire, nearby populations would have been exposed to escaping chlorine gas. As many as 14 separate evacuations were ordered during the incident as a consequence of new hazard information coming to light (Burton et al. 1981). Estimation of the hazard is often facilitated through prior knowledge and training.

4.1.1.3 Definition of Magnitude

Sometimes it is difficult to accurately forecast the magnitude of an impending hazard. For example, it is difficult to foretell the precise windspeed of hurricanes at landfall. Because of the inexactness of our ability to predict magnitude, uncertainty regarding the advisability of public warning often cannot readily be resolved.

There are magnitudes of events for which warning and evacuation is advisable and others for which they are not. Uncertainty can lead to wrong warning decisions. It can also delay warning and evacuations. The Rapid City flood is a case in point (Mileti and Beck 1975). Heavy rains and rising water levels in the creek were both detected. However, the magnitude of the flood event was not accurately foreseen; those estimating magnitude did not know that a natural dam in a canyon above the city had broken. The lack of this knowledge delayed the timely issuance of warnings, led to ambiguity concerning what protective actions to recommend, and resulted in significant losses. Magnitude estimation is typically more accurate if it is based on available technology and if knowledgeable personnel are working with the information.

4.1.1.4 Self-Definition of Role

Uncertainty in the performance of warning-related work has affected both those who initiate communication and those who receive it. People uncertain about their communication role in a warning system do not always perform it. Uncertainty on the part of those who play key parts in the chain of communication can slow activation of the system because key players who are uncertain of their role often do not convey risk in a timely manner. For example, the

mining company responsible for creating the slagheap reservoir on Buffalo Creek did not define its role as that of emergency responder or communicator. As a result, when the dam failed, no timely alert was given to public officials who could have issued a public warning (Erikson 1976). People are more likely to understand their role in a warning system if plans exist and training occurs.

4.1.1.5 Sorting of Relevant Information

Sorting relevant from nonrelevant information is needed when there is either too much or bad information facing the decision maker. It is then necessary to determine which pieces of information should be used to make a decision and which should be ignored. For example, a local sheriff who must decide whether to activate an evacuation alarm system in the vicinity of a hazardous chemical spill might be given recommendations from different organizations, as well as meteorological data, projected dose rates, and so on, until the sheriff is overwhelmed by the amount of information. In such cases, the decision maker may exclude some information and make a decision on the basis of partial information. Another possibility is to ignore the information and make the decision on the basis of some exogenous factor. This uncertainty in how information is sorted can reflect itself in the quality of the warning decision. For example, when Mount St. Helens became active, emergency response organizations were given raw data on seismicity and plume activity. In the course of trying to understand and use these data, they tended to neglect some responsibilities, such as providing warnings to the public (Sorensen 1981). Warning system plans that anticipate such problems and which provide for the communication of only important understandable information help to solve this problem.

4.1.1.6 Definition of Authority

In a warning system, authority may be defined as the way in which the various actors in the system perceive the responsibility and power of other actors to make decisions. The relative disposition of authority can create uncertainties in several ways. First, disputes can occur if more than one person or agency assumes a leadership role. Second, information may not reach the right decision makers if authority roles are perceived incorrectly. Third, decisions could be delayed or overlooked if no one takes charge because that level of authority is perceived as someone else's responsibility. This was a problem among agencies and private corporations preceding the large eruption at Mount St. Helens (Sorensen 1981). Disagreement over evacuation authority arose between the U.S. Forest Service and a lumber company. The Forest Service wanted to evacuate lands that were being harvested. The conflict led to a series of revisions in warning policies with compromises on both sides. Fortunately, the eruption occurred on a Sunday, when no logging was taking place. Plans that define authority before warning events occur can do much to reduce this problem.

4.1.2 Communication Dilemmas

Public advisement and warnings are usually the results of long chains of communications between different people in different organizations. Consequently, a key to understanding the warning decision-making process is to view it as a series of communications between both people and organizations. This process of communication has produced uncertainties in past

emergencies, constraining warnings and protective action by the public. These uncertainties fall into four categories: (1)whom to notify, (2)ability to describe a hazard, (3)physical ability to communicate, and (4)conflicting information.

4.1.2.1 Whom to Notify

Uncertainty about who should receive hazard information has constrained the communication process in some past warning situations and delayed public response. Sound hazard recognition and an accurate determination of threat cannot be useful unless that information is communicated. Dissemination of threat information to communities at risk can be constrained if the persons possessing hazard information do not know what local agencies—and which people within them—to notify. For example, at MountSt. Helens, warnings concerning ashfall levels and their consequences to eastern Washington were not given. This failure has been attributed to the lack of predisaster interactions between state and local emergency organizations and to a lack of knowledge about whom to contact when the volcano erupted (Saarinen and Sells 1985). Warning plans should specify the appropriate notification sequence.

4.1.2.2 Ability to Describe Hazard

Those engaged in providing hazard information to others have created uncertainties because of the way threat descriptions were worded. Nonscientists, for example, rarely share a common understanding of probabilities with scientists, much less with one another. Vagueness in the specification of risk areas can lead to increased uncertainties for those confused over whom to warn. Technical descriptions of the physical processes associated with a hazard may mean little to those interested in only simple definitions. The inability of some scientists and technicians to describe hazards in clear and simple ways has created uncertainties for those who must use that information to make decisions.

This inability also has created uncertainties in the process of communication leading up to protective action advisement. For example, when there was an explosion at a chemical plant in Taft, Louisiana, the evacuation of the surrounding population was delayed by the failure to communicate accurate information about the explosion and its potential consequences (Quarantelli 1983). Company officials did not explain the accident in terms that local officials could readily use in making their decisions. Even when they issued a warning that recommended a 5-mile evacuation, local officials did not understand why it should be that distance. In the 1985 eruption of the Nevado del Ruiz volcano, a poor description of the hazard contributed to the loss of 24,000 lives. After the eruption, national television broadcast the message that there was no cause for alarm. Several hours later a devastating mud flow destroyed the town of Armero (Voight 1988). Training or the use prescribed messages might have helped to address this problem.

4.1.2.3 Physical Ability to Communicate

Loss of technical capacity to communicate has been a source of uncertainty in many prior warning situations. Some reasons include the nonmatch of radio frequencies, the lack of dedicated phone lines when regular lines are overloaded, and the lack of back-up communications systems when planned or routine systems fail. A good example of a physical communication failure is provided by the 1977 Johnstown flood. The loss of the phone system hampered efforts of the

Corps of Engineers' weather observer to transmit rainfall data to flood forecasters and, consequently, efforts of NWS to alert local officials (NWS 1978). Technical hardware to provide for communication between different entities in a warning system should be resilient when damaged and redundant to provide for backup communication mechanisms.

4.1.2.4 Conflicting Information

Conflicting data or recommendations can lead to different conclusions about whether to issue a warning. The decision maker must then decide which information is valid. For example, if a local official in charge of warning receives information from one source that a dam has overtopped and from another that it is sound, a decision on whether to warn people to evacuate may be delayed. A bad decision may result if erroneous information is acted upon.

This type of situation was encountered in 1983 with Hurricane Alicia. Local officials relied on official forecast information from both NHC and the Galveston National Weather Service Office. The local weather service was warning officials that the hurricane could take a northerly turn and hit Galveston. The NHC was concentrating on warning of a more southerly landfall. Galveston officials played down the potential of Galveston's being affected, and it was too late to evacuate when the storm turned (Savage et al. 1984). This problem can never disappear entirely; however, efforts to minimize the chances of it occurring can be undertaken. Pre-event plans can formalize who makes such judgments and to whom they are communicated to avoid conflicting reports. The quality of those judgments are, however, limited by technology and those organizations and people involved.

4.1.3 Perceptual Dilemmas

Uncertainties also exist in the warning process because of decision makers' perceptions regarding the negative impacts of making wrong decisions. Some of these perceived impacts have no basis in reality and are instead part of a general myth structure about public emergency response. Others are potentially real. Six categories of negative impacts, identified from past events, include public consequences, personal consequences, unnecessary costs, liability, evacuation feasibility, and outside expectations. Having plans that classify events into categories that are followed by predesignated actions can do much to relieve the impact of perceptual factors.

4.1.3.1 Adverse Consequences

Warning decisions can be influenced by a decision maker's perception of the adverse consequences of action. For example, in an evacuation typical concerns may be that people will panic, be hurt or killed, or that homes will be looted while residents are away. While such events may occur in some isolated and unusual circumstances, such beliefs are largely unfounded given previous experiences. Despite evidence to the contrary, however, the belief still persists that such problems are typical rather than rare events. In addition, decision makers may believe that a false warning will hinder future warning needs (the "cry wolf" syndrome). There is little evidence that this is the case.

For example, in Hurricane Carla, the state government decided against issuing a warning for a general evacuation for fear of panic and unnecessary movement. Instead, it let local

governments make decisions (Moore et al. 1963). In Hurricane Alicia, several local governments, having ordered evacuations that proved unnecessary for Hurricane Allen, decided not to issue an evacuation warning for fear of being wrong again (Savage et al. 1984).

4.1.3.2 Personal Consequences

Uncertainty has led to apprehensiveness in notifying other organizations and the public about an impending threat. Often this results in downplaying the potential threat when it is communicated. Decision makers have feared that transmitting risk information for a threat that might not materialize could lead to personal consequences such as loss of reputation or image or loss of votes in a future election. For example, in a 1965 tsunami threat situation in Crescent City, California, local officials feared public sanctions if they called for another evacuation and no tsunami occurred (Anderson 1970).

4.1.3.3 Costs of Protective Actions

Decision makers also can be influenced by their perceptions of the dollar costs or losses that may stem from warning, particularly when the warning is precautionary. Costs may include transportation and sheltering of the public, as well as costs for emergency personnel. Losses can include revenues lost from employment or sales, damages incurred from injury during evacuation, or losses from the shutdown of productive sectors in an economy. A city that has exhausted its emergency funds and cannot easily pay for police overtime may be reluctant to issue a warning. Perceived economic costs played a significant role in determining evacuation zones at Mount St. Helens. Evacuation boundaries were shifted to divide the cost of manning roadblocks between two counties and to allow access to economic enterprises in the area (Sorensen 1981).

4.1.3.4 Liability

How agencies, organizations, or the actors within them perceive liability also can influence warning decisions. Liability for public safety is frequently an issue for public agencies. The major concern is over responsibility for damages if a disaster occurs and actions are not taken to protect the public. In such cases, victims may claim both compensatory and punitive damages for a failure to warn (Davis 1986). In fact, a recent court case resulted in a jury awarding \$16.2 million in punitive damages to 65 residents who were not warned of the hazards of a dioxin spill (Right to Know News 1987). This perception can cause officials to err on the side of caution. On the other hand, decision makers may perceive themselves as being liable for ordering an unneeded evacuation that leads to unnecessary costs and possible evacuation-associated damages. A recent earthquake prediction issued by California Institute of Technology scientists for the San Diego region did not lead to a warning from the state. One reason for silence was confusion about liability for issuing a public warning (Southern California Earthquake Preparedness Project 1985). Liability concerns can be reduced if pre-event legislation relieves warning system actors of it; this type of legislation exists in some states for some hazards.

4.1.3.5 Feasibility

Feasibility refers to the potential success of a warning in regard to successful public protection. Perceptions of the feasibility of specific public actions can be influenced by factors such as the severity of the hazard, geography, safety of evacuation routes, and the like. Misperceptions of feasibility could lead to poor decisions concerning a warning or influence the timing of warning decisions. For example, the fear of radioactive release during a fast-moving accident at a nuclear plant, in conjunction with poor weather, could lead to a warning advising evacuation even before plant conditions suggest that an evacuation is in order. In Hurricane Alicia, Galveston officials did not issue an evacuation warning because they felt there was insufficient time for all to leave before the storm hit (Savage et al. 1984).

4.1.3.6 Expectations

Warning decisions can be influenced by the expectations or demands of persons outside the warning system environment. A public official, for example, may perceive that a warning and evacuation is expected by the public. In addition, a decision maker may feel pressure from another level of government or from some other agency when deciding whether or not to issue a warning. At times such pressure may be counterproductive, causing the responsible official to overreact and follow the opposite course of action. During the Three Mile Island accident, the decision by Pennsylvania's governor to recommend a selective evacuation was partly a response to outside demands and pressures to demonstrate control and leadership (Dynes et al. 1980). During the approach of Hurricane Alicia, evacuation communication from the governor of Texas to the mayor of Galveston may have played a role in the early decision not to evacuate. In this case, the mayor may have reacted negatively against the state's position instead of making a decision independently of the state.

4.2 FINDINGS FROM RESEARCH ON WARNING ORGANIZATIONS

The effectiveness of detectors and emergency managers in performing their organizational duties in warning systems can be and has been constrained by dilemmas of interpretation (i.e., is the impending event hazardous, who should do what as part of the warning process, do those persons possess the authority to proceed, what information is important vs unimportant); by communication dilemmas (to whom should what be said, how can conflicting reports be resolved, is there the ability to contact others); and by dilemmas of perceptual constraint (will a warning have an adverse impacts, is there the potential for liability). Fortunately, these constraints can be managed.

Research over the last three or so decades has discovered several factors that affect organizational effectiveness in warning systems and in emergency response in general. It is the purpose of this part of this section to summarize those research findings. What has been learned is divided into four categories: (1) establishing organizational effectiveness when performing a warning role, (2) dealing effectively with other organizations during warning events, (3) integrating the warning system, and (4) maintaining flexibility during times of warnings. Appendix A provides a catalogue of research evidence to support the findings discussed in the remainder of this chapter.

4.2.1 Organizational Effectiveness

One focus of research has been to determine what factors inside an organization facilitate effective performance during emergencies. Each warning system organization could address these issues to avoid internal organizing dilemmas and increase the effectiveness of its warning role.

1. Identify all the warning tasks for which the organization is responsible. If an organization has multiple divisions, differentiating the role that each plays in a warning is recommended. This issue is particularly important in organizations where emergency work is not routine.
2. Specify clearly who has authority and responsibility for each task. The specification of the authority hierarchy within and among tasks can help prevent unnecessary disputes during an actual emergency. During an emergency, authority (in most organizations) shifts from that of routine operations. For example, the person who is routinely in charge of a scientific research organization may not be the person in charge of issuing volcano warnings when threat is detected.
3. If multiple tasks and authorities exist within the organization, it is helpful to identify the relationships between each. It is useful to establish the boundary between activities if they are closely related to each other. For example, if one group is responsible for preparing the content of a warning message and another for approving it, it would be desirable to understand the formats for each job to avoid duplication and conflict.
4. When time and resources can act as constraints, designate emergency priorities in the warning plan. The effectiveness of the organization can suffer if this is not addressed in plans.
5. Examine the similarities and differences between normal work tasks and emergency work functions. In general, the less the members of an organization have to change from their normal routine to do emergency work, the more effective they will be in an emergency. Organizations whose daily operational routines can be used in the emergency do better than organizations that must adopt new ways to do work that are unique to the emergency. For example, if the person in charge of press releases normally expects a secretary to do the typing and a secretary will not be provided during an emergency, that person may experience problems in issuing the press release. Mobilization is quicker and less problematic for organizations whose normal duties resemble emergency duties. Disaster experience and training both help remove this constraint since they make unique emergency duties more familiar to workers.
6. Emphasize the importance of the organization's role in the warning system. The people who perform warning roles in organizations should view their responsibilities as important to the overall objectives of the emergency response effort. Otherwise, the performance of warning responsibilities can be seriously undermined. When responsibilities are taken seriously, work group cohesion and work effectiveness is enhanced. Likewise, people should believe it is important to perform their warning responsibilities because the hazard threat will, in fact, materialize. If people do not believe that the disaster will occur or believe an alert is a false alarm, they are less likely to act.

7. Ensure that roles and tasks are well known and understood. Little is accomplished in developing a plan if people do not know or understand their own responsibilities and those of others before the warning is needed.
8. Open communication channels from a physical as well as a cognitive perspective. If people who need to communicate in an emergency do not normally do so, it is helpful to use exercises or other means to let them communicate before an actual warning situation exists. Isolated people and organizations that receive little or late information also are less likely to get information and pass it along to others.
9. Document what decisions will be made by the organization, who will make them, and how and when they will be made. This type of planning can help avoid surprises and eliminate poor decisions in the emergency.
10. Provide warning organizations with adequate resources (people and hardware) to do the job. While organizations are usually adaptive in obtaining resources, pre-emergency agreements to assure adequacy are desirable.

4.2.1 Dealing with Other Organizations

A second focus of research has been to explore why organizations are or are not effective in dealing with other organizations in emergencies. These findings are useful for understanding warning systems, since one system is typically comprised of many organizations (see Sect.2).

An overriding conclusion of research is that coordination between organizations is essential. Commonly, the finding is that coordination is poor. Research documents many useful factors that help achieve coordination between organizations. Many of the factors facilitating interorganization coordination are the same as those discussed in the last section:

1. Understand the roles and responsibilities of other warning system organizations. This understanding helps an individual organization do a better job and increases the effectiveness of the entire warning system. Shared knowledge about responsibilities increases coordination between organizations. In addition, if everyone who has a warning system job is aware of the duties of others, more people will understand the boundaries of their work and how all parts of the system fit together.
2. Establish clear lines of authority between organizations with related jobs in the warning system. Clear authority lines between organizations help to expedite decision making, avoid conflict between organizations, and facilitate interaction between organizations in the system. When authority is unclear, competition for authority can focus attention away from emergency responsibilities.

These first two factors help to define and legitimate the range of related warning system jobs across organizations. When these two steps are carried out, all involved organizations are seen as legitimate and important parts of the system by all other organizations. Such a viewpoint facilitates coordination between organizations and enhances system effectiveness. If an organization is not viewed as legitimate, it can be excluded from communications even if it has an important responsibility.

There are six other factors in effective interorganizational coordination:

3. Establish agreements regarding priorities. In some cases, priorities between organizations may differ from those within organizations. If so, potential conflicts need to be understood and avoided.
4. Limit the number of organizations involved in the warning system. This is sometimes difficult to accomplish because warning systems tend to involve many organizations almost by definition, but a multitude of organizations cannot be easily coordinated. The number of organizations that can readily be coordinated increases with the availability of resources, and especially communications equipment. Also, it is usually easier to coordinate local organizations with each other than with those from outside the area since local groups are more likely to interact with each other during routine operations. Often, outside organizations on the scene some time after the onset of the disaster create conflict and uncertainty.
5. Identify where compatibility and cooperativeness with other organizations exists and where it is a problem. Where problems do exist (e.g., disputes between city and county fire departments), it may be possible to eliminate or reduce the impact on a warning system. If problems cannot be eliminated, their recognition may be helpful in dealing with disputes in an emergency.
6. Establish system oversight. An interorganizational panel, board, or committee is often useful for this purpose. Representation in that oversight organization increases an individual organization's effectiveness through enhanced coordination.
7. Establish efficient communication between organizations in a warning system. Communication between member organizations is critical because a warning system is a communication system. Efficient communication depends on resources and pre-emergency patterns. Organizations are more likely to communicate during an emergency if they do so routinely. When routine communications do not exist between organizations, drills to exercise the warning system may be particularly useful.
8. Be aware that organizations can resist giving up autonomy to participate in an emergency warning system because some command and control comes from outside the organization. This can be a major constraint to system coordination. Participating organizations need to be convinced that some loss of autonomy is worth experiencing in exchange for an effective warning system.

4.2.3 Integrating the Warning System

Ultimately one organization or person is in charge of a warning system. The goal of this entity is to make sure that the entire warning system functions effectively. This requires some degree of integration among the many different parts of the system. Several activities facilitate integration.

1. The lead warning agency should make sure that the expectations about the responsibilities of all participating organizations are known and shared. If participants have different perceptions of what others do or are responsible for, gaps in the warning process may occur ("I thought they were going to do it"). In addition, the lead agency has the

- responsibility for making sure each organization accepts the responsibility of all other participants in the system and resolving problems if they occur.
2. The lead agency should estimate the resources needed for implementing a warning and assess and inventory what resources are and are not available. When deficiencies exist, linkages should be established to share resources or a plan should be developed to obtain permanent or emergency resources.
 3. The lead agency should assume responsibility for developing smooth-running relationships between all organizations in the system. This may involve cataloging which personnel in each organization to interact with or deciding who will be sent to serve on an advisory or oversight group. The lead agency should also make sure that the structure of authority in an emergency is comparable to existing relationships. If organizations do not interact, the lead agency needs to increase interaction and make sure that interaction benefits each organization involved. Communication should be clear and open. Situations in which one organization uses the warning system to achieve other goals must be avoided.

4.2.4 Maintenance of Flexibility

A major problem facing many warning systems is maintaining vigilance and flexibility over time. Watchfulness lags because warnings are often not needed for long periods of time. Agreements or plans grow old and are forgotten. Furthermore, flexibility is threatened by overly rigid rules and procedures, particularly when the rationale for the procedure is forgotten.

It is important for organizations to develop rules and procedures that are general enough to adapt to unforeseeable emergency conditions and contingencies. Overly detailed plans are not desirable; instead, plans should reflect principles for response. This is not to say that certain standard procedures or details outlined earlier are not warranted.

A key to maintaining flexibility is to conceptualize warning as a planning process instead of the preparation of a document or a plan. Frequent testing and updating of the system will help maintain knowledge useful for adaptive warning response. The research literature firmly supports the idea that organizations that are better able to vary from standard operating procedures during the disaster are typically more effective than those that cannot be flexible.

4.3 CONCLUSIONS

Emergency planning for warning systems is not always necessary for warnings to be successful. History is riddled with examples of very effective public warnings in communities without warning system preparedness. Unfortunately, history catalogs other cases where warning systems failed or suffered from organizational flaws in organizational procedures and equipment. Planning increases the odds that warning systems will be effective when they are needed. Effective warning systems require that planners seek to achieve two goals.

First, planners should do all they can to minimize the natural tendency for organizational dilemmas to plague warning systems. Warning system actors should be as free as possible from problems of interpreting risk, hazard, their role in the system, authority, and relevant versus nonrelevant information. Communication problems such as who and how to notify should be removed. In addition, happenstance perceptual dilemmas based on personality quirks, perceived

fears and apprehensions, and experience should be addressed and removed through organizational aspects of planning.

Second, those responsible for warning systems should clearly recognize and incorporate both the organizational and interorganizational character of warning systems and preparedness. It must be clear who does what when; and those persons or groups must have the ability and authority to do it. These actors, and the organizations they represent, must be integrated as part of an interorganizational system. The timely and open exchange of clear information must be facilitated. Finally, people must be well trained, but the plan must provide for on-the-spot flexibility in order to adapt to unanticipated circumstances.

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5. PUBLIC RESPONSE ASPECTS OF WARNING SYSTEMS

Social science research on public response to warnings of impending disaster began in the 1950s as part of the research program in the National Academy of Sciences (NAS). These investigations examined human response to both natural and technological emergencies. Research continued in the 1960s by individual researchers. In the 1970s and 1980s, warning response studies placed less emphasis on describing human response and focused on discovering how single factors (like sex or age) covaried with public behavior. Most current studies attempt to model the effect of complex sets of factors and their interactions on warning response. Consequently, existing empirical studies vary widely in terms of methodological soundness, theoretical quality, the hazard type being studied, the type of public behavior being studied, and in the basic reasons for conducting the study.

In this section, we synthesize what is known based on the record of empirical research on public warning response. We begin by describing our conceptualization of the social-psychological process that people go through in a warning situation from the time a first warning is heard to the time people respond. The second part of this section defines the factors documented by research as the reasons people think and do different things in response to warnings. The third part summarizes how these factors impact the warning response process (also see Appendix B). The final part of the section summarizes how to use knowledge about public response in designing and implementing a warning system.

5.1 THE WARNING RESPONSE PROCESS

Why can different perceptions of risk arise among the members of a public who all receive the same warning message? Why can public response to a warning differ between individuals who all receive the same information about how to respond? In this section, we outline the basic social-psychological process that underlies these differences.

Human decision making about warnings resembles an ordered-choice or lexicographic decision process. People go through a more or less sequential process in which they consider various aspects of the decision confronting them before acting. The sequence may not be the same for every person warned. Moreover, each stage is not necessary for a response to occur. The process is initiated by notification or hearing an initial warning. This, in turn, leads to various psychological and behavioral outcomes, and the process is shaped by sender (those issuing the warning) and receiver (those hearing the warning) factors.

5.1.1 Hearing

The first stage is hearing the alert or warning. It cannot be assumed that just because a warning is broadcast or a siren is sounded people will hear it. Even when it is physically possible to receive the warning, the warning may, so to speak, fall on deaf ears. People may fail to hear because of habituation (e.g., they never really listen to television), selective perception (e.g., they hear only what they want to), or physical constraints (e.g., they are out of range of the siren system). Regardless of the reason, the failure to hear a warning generally precludes or at least delays response.

5.1.2 Understanding

Once heard, the warning must be understood. Understanding does not refer to correct interpretation of what is heard, but rather to the personal attachment of meaning to the message. Meaning or understanding can vary between different people, and these varied understandings may or may not conform to the meaning intended by those who issued the warning. For example, one person may understand a flood warning as a high wall of inundating water while another may conceive of ankle-high runoff. Ashfall may be construed as a suffocating, blanketing coverage, or as a light dusting of powder. A 50% probability may be interpreted as certainty by some or unlikely by others. In this sense, understanding also defines and bounds perception of risk and what to do about it.

5.1.3 Believing

Once an understanding is formed, people then determine whether or not to believe that the warning is real and that the contents of the message are accurate. Believability is influenced by many factors associated with the method and contents of the warning. The classic referenced case is the "cry wolf" syndrome. If warned often and falsely, people, it is feared, will not believe a true warning. While this may be a legitimate concern in some cases, it has not been proven to be true for warnings in general.

5.1.4 Personalizing

People think of warnings in personal terms—that is, in terms of the implications of the risk for themselves, their families, or their group. If people do not feel that they are the targets of the warning (even though it may be understood and believed), they may well ignore it. This is illustrated by the "it can't happen to me" syndrome, in which people deny the existence of a risk for which they have been warned. Personalizing a warning is an important step that facilitates a response to the warning.

5.1.5 Deciding and Responding

At this stage a person has heard the warning, formed an understanding about what was heard, developed a level of belief about what was understood, and decided whether or not he or she will be personally affected by the risk when it materializes. The next step in the process is to decide what if anything to do about the risk. In general, people do what they think is best for them to do. This is sometimes interpreted as irrational behavior by an observing expert, but it is in fact typically rational for the person engaged in the response. Moreover, making a response decision does not automatically lead to acting on that decision, since events may prevent intended behavior from occurring. For example, a family may decide to evacuate, but a missing pet may delay or prevent the relocation.

5.1.6 Confirming

A person typically goes through the stages of the model just outlined each time new warning information is received. Thus, response is not the result of a single decision but is instead the eventual consequence of a series of decisions. Additionally, during the emergency warning period people do not passively await the arrival of more information. Instead, most people actively seek out additional information. Seeking new information to confirm prior information, or receiving new information which confirms prior information, has typically been referred to as the warning confirmation process. When warning information is received, most people try to verify what they heard by seeking out information in another warning message or from another warning source or person. Confirmation is the main reason that telephone lines can become busy after a public emergency warning is issued; people call friends and relatives to get their interpretations of the event and to find out what they are going to do.

The confirmation process occurs because people are information hungry following receipt of warnings. Rarely are people overwhelmed by information in a warning context. Instead, there is an information void caused by uncertainty, particularly when rare or unfamiliar events are about to occur. This void typically creates a public demand for more information than is being disseminated in the warning message. In addition, it creates a need for repetitive warning messages to enable people to absorb all the knowledge they wish to possess.

Confirmation plays an important role in the general warning response process. It is ongoing and affects each stage in the process. It helps people better understand warnings, believe them, personalize the risk, and make response decisions.

5.2 THE FACTORS THAT AFFECT THE WARNING RESPONSE PROCESS

Research findings suggest that variation in the warning response process occurs for a variety of reasons. All of these reasons focus upon differences in the warnings themselves as well as between members of the public who receive warnings. We refer to the former as sender determinants because they deal with aspects of the actual warnings sent to a public (e.g., frequency of repetition and named source). We refer to the latter as receiver determinants because they describe the ways that members of the public can differ one from another (e.g., sex, age, and prior disaster experience). It is our intent to define these sender and receiver factors.

5.2.1 Sender Factors

We have defined only those sender factors that research has demonstrated as having an impact on the warning response process. These sender factors have been grouped into four categories (Fig.5.1). These categories are attributes of (1)the warning messages themselves, (2)-the channels through which the messages are given, (3)the frequency with which messages are given, and (4) the persons or organizations who are the sources of the warning messages.

MESSAGE ATTRIBUTES
Content (location, guidance, risk time, source)
Style (specificity, accuracy, consistency, certainty, clarity)
CHANNEL ATTRIBUTES
Type
Number
FREQUENCY ATTRIBUTES
Number
Pattern
SOURCE ATTRIBUTES
Officialness
Credibility
Familiarity

Fig. 5.1. Typology of sender characteristics.

Message attributes deal with both message content and message style. Message content consists of four components: (1) information about the location(s) at risk and not at risk; (2) information about the character of risk, for example, the depth of expected flood waters; (3) information about guidance, or what people should do to protect themselves; and (4) information about how much time there is before impact or before a protective action should be initiated or completed. The style of a warning message has five components: (1) specificity, or the degree to which the message is specific about risk, guidance, location, and time; (2) consistency, or the degree to which the information in a message or across different messages is consistent and not contradictory; (3) accuracy, or the extent to which message content is correct; (4) certainty, or the degree to which those giving the warning message seem certain about what they are saying; and (5) clarity, or the extent to which information is stated clearly and in words which people can understand.

Attributes of the channels through which warning messages are disseminated refers to the actual medium used to transmit a message, whether television, radio, route notification, face-to-face communication, or others (Fig. 5.1). Channel number simply refers to the number of different warning channels used to get the word out.

The frequency with which warning messages are disseminated is divided into two characteristics. First is the number of times a particular warning is repeated or conveyed to the public. Second is the degree to which message repetitions occur in a predictable pattern, for example, every 15 min, randomly, or not at all.

The last category of sender factors is source attributes, which refers to the person or organization disseminating the warning message. Three factors have been demonstrated as being important: (1) the level of familiarity of those giving the message to those receiving it; (2) the degree to which the message giver is perceived to be an official source; and (3) the perceived credibility level of the message giver.

5.2.2 Receiver Factors

The many factors relating to the characteristics of the people who receive warnings have been grouped into the following four categories (Fig. 5.2): environmental, social, psychological, and physiological.

ENVIRONMENTAL ATTRIBUTES
Cues (physical, social)
Proximity (distance, time)
SOCIAL ATTRIBUTES
Network (family and community)
Resources (physical, social, economic)
Role (age, gender, responsibility, status)
Culture (ethnicity, language)
Activity (sleeping, working, engaging in recreation)
PSYCHOLOGICAL ATTRIBUTES
Knowledge (hazard, protective action, plans)
Cognitions (stress, fatalism)
Experience (type, recency)
PHYSIOLOGICAL ATTRIBUTES
Disabilities

Fig. 5.2. Typology of receiver characteristics.

Environmental factors are largely those cues which either do or do not support the warning information that has been received. Cues can be physical; for example, it is raining heavily when flood warnings are received. Cues can also be social; for example, neighbors are seen evacuating when evacuation warnings are received.

The social attributes of the warning receiver have been grouped into five categories:

1. Aspects of the social network of which the warning recipient is a member. This category includes such factors as whether or not the family is united when the warning is heard, social ties and bonds, or the existence of nearby friends and relatives.
2. Resource characteristics of the warning recipient. This category refers to physical resources, such as having or not having access to a car in which to evacuate; economic resources, such as having or not having the money to pay for a hotel; and social resources, such as having or not having a local social support system of friends, church, or community groups.
3. Aspects of the role of the warning recipient, such as sex and age and being a parent.
4. Cultural characteristics, such as ethnicity, and language.
5. Activity characteristics of the warning recipient. Response can vary depending on whether the receiver is sleeping, working, or participating in recreational activities.

The third set of attributes of the warning recipient relates to psychological characteristics. These include knowledge about the risk associated with a particular hazard agent, about protective actions, and about the existence of emergency plans; cognitions such as psychosocial stress level and sense of personal efficiency of the warning recipient; and previous experience with the hazard agent.

Finally, there are physiological attributes. Physical disabilities such as deafness and blindness can affect the warning process; disabilities such as mobility impairment can affect warning response.

5.3 A SUMMARY OF RESEARCH FINDINGS

In Sect.5.3, we summarize research findings on how sender and receiver factors affect the hearing, understanding, believing, personalizing, deciding, responding, and confirming elements of the warning response process. (The actual findings from specific research studies are catalogued and referenced in Appendix B).

5.3.1 Hearing Warnings

Relatively few empirical findings exist in the research literature on why some members of the public hear warnings of impending disaster while others do not. It is possible that few researchers have thought to study this factor because many assume that a warning is heard. Enough evidence exists, however, to conclude that it would be imprudent to presume that all members of a public would hear a warning just because one is issued. In addition, research evidence does exist to document that hearing a warning is influenced by both sender and receiver factors.

5.3.1.1 Sender Factors

The information channel used for disseminating emergency public warnings has a clear effect on the number of people in an endangered public who hear the warning. The mass media is typically the most effective, and the broadcast media have been the primary source of hearing warnings among all available types. Some studies found that television is more effective than radio; however, an equal number of studies found the opposite. It has been found that the electronic mass media are more effective initially, but that newspapers become a more important source in the case of long-term warnings that extend over several days or weeks. It has also been documented that personal contact with the public can be an effective way to increase the number of people who hear a warning. In all cases, the more that different information channels are used to disseminate warning messages, the more people who hear and remember that they have heard a warning message.

The findings on the effect of sender determinants on enhancing the hearing of warnings by an endangered public are relatively scant compared to other topical areas in public warning response research. The empirical base is also limited in the sense that findings rest largely on simple statistical analyses in single case studies, rather than on hypothesis-testing studies. Nevertheless, evidence in the research record suggests that the number of people who hear a warning message can be maximized if multiple electronic mass media channels (radio and television) are used to issue a public warning, supplemented by personal contacts with the public and by the use of the printed mass media (i.e., newspapers) in the case of long-term warnings.

5.3.1.2 Receiver Factors

The research available on the effect of receiver factors on the probability of a member of the public hearing an emergency warning suggests three findings.

First, some members of society are more likely to hear a warning because they are part of a social network (association member, community system, kinship network, subculture) or are in a social role (higher socioeconomic stratum, young, female, parents) that leads them to have more links to other community members who might give them informal warning notification. Even these people, however, have a lesser chance of hearing a warning when removed from access to their social networks, for example, when they are engaged in activities away from home or work. Informal notification is also less likely, and consequently hearing a warning is less likely, for people not in close proximity to a potential disaster site since their social networks would probably contain fewer contacts with people who already have received a warning.

Second, some people are less likely to hear a warning because they are less quick to pick up on the cues around them or make interpretations that would lead them to seek out a warning. Such people, for example, would be those without environmental cues; those without disaster experience, knowledge, or a contact who knows about the hazards; and those that have fatalistic cognitions.

Third, there are some people with physiological constraints to hearing a warning. The physical impairments of the deaf and blind could delay from their receipt of a warning. In practice, however, such impairments may not retard receipt of a warning. Friends, neighbors, relatives, and other intimates may give informal notification.

These findings suggest that the number of people in a public who receive a warning can be maximized in theory by (1) planning to capitalize on the natural tendency for informal notification

to carry warning messages to others; (2) providing cues (e.g., the use of sirens) which very few could ignore; and (3) planning to overcome the physiological constraints that could keep some from hearing a warning.

5.3.2 Understanding, Believing, Personalizing, and Responding to Warnings

Research findings document that warnings are more likely believed if they are based on a clear understanding; warnings are more accurately personalized if they are understood and believed; and warnings are more likely to be responded to with some protective action if they are understood, believed and personalized. These findings suggest that each of these social-psychological factors are important in understanding and predicting public warning response. Interestingly, and for all practical purposes, the sender and receiver factors which impact each of these warning response process factors are almost identical.

5.3.2.1 Sender Factors

The research record points out the characteristics of warnings that maximize the probability that they will be correctly understood, believed, personalized and acted upon. The most effective warnings are those which are specific about impact location, protective actions, the time to impact, and the character of risk. Also, they are consistent and certain, they address why they should be acted on if the probability of impact is not very high, they are delivered through multiple channels of communication, they are often repeated, and they are labeled as coming from a panel of officials, scientists, and experts to enhance the credibility of the information in the warning. No single warning source is credible for everyone. Warning information that is inconsistent, vague and unclear result in a confused public and misunderstandings about what to do, why, and when.

Also, it is typical for any warning situation to be characterized by different and inconsistent warnings from a range of sources, for example, official warnings versus informal ones from neighbors. Official and frequently repeated warnings can help people focus on authoritative messages rather than on warning from other nonofficial sources. Frequent repetition also increases the odds that warnings will offer consistent rather than inconsistent information.

5.3.2.2 Receiver Factors

The evidence provided by research studies suggests that there are differences among the people who receive warnings that impact warning understanding, belief, personalization and subsequent response.

First, some members of the public are better equipped to process and respond to warnings because of pre-emergency knowledge about the hazard and appropriate response, education, socioeconomic status, experience, resources to facilitate response, and the lack of physiological constraints.

Second, some people are in positions that act as incentives to process and respond to warnings. These include being in positions of responsibility for others, observing environmental or social cues that confirm the risk or response, having a perception of personal risk because of close proximity to the impact area and therefore access to less distorted information, and access

to a social network like friends and family to talk to and enhance response options like evacuation.

Third, some people are in positions or of a character that act as constraints to processing warning information and to response. These include, for example, the tendency to follow habit, membership in minority subcultures that distrust main-culture authority, a general tendency to prefer to engage in some protective actions as a united nuclear family, and having fatalistic cognitions.

These findings do not mean that members of the public who fit a profile that would predispose them to poor warning response must be destined to such an outcome. They do suggest that sender attributes of warnings are more important in facilitating good public perceptions and response among some members of the public than among others, for example, people with little education, those who do not see environmental cues, and those who are members of a minority group subculture. Warning response as illustrated in historical emergencies suggests that some people process emergency warning information well, while others do not, simply because of who they are. This underscores the need for warning plans that address sender factors to give all members of the public an equal or good chance to interpret and respond well to warnings in an emergency.

5.3.3 Confirming Warnings

Confirmation of a warning is a typical public response to receipt of a warning message. It affects eventual protective action response by enhancing the understanding of, belief in, and personalization of original warnings. Research indicates that confirmation is a positive function of lead time, perceived personal risk, messages received from the mass media, and family unity. It is a negative function of the number of warning messages received (which is itself confirmation), prior knowledge about the hazard, and the level of specificity contained in the original warning received. It seems, therefore, that confirmation attempts are most likely when the original warnings are not repeated (or not repeated often enough) and lack details. It is apparently difficult for the public to perceive risk and act on the basis of limited initial warnings. People seek out and need additional information to be convinced that they should engage in protective action.

5.4 USING RESEARCH KNOWLEDGE

Studies over the last several decades have addressed public warning response in a wide variety of climatological, geological, and technological events. Research has been of varied types. Some studies have been descriptive, while others tested hypotheses. Some have used sophisticated multivariate analysis, while most have instead been content to explore the character of a few hypotheses based on simple statistical tests of correlation and significance. Despite a rich variety in method, approach, and analysis technique, the accumulated database can be cataloged, as we have sought to do in the preceding parts of this section and in Appendix B. These data can then be viewed at a higher level of abstraction to answer the question, "what operates to determine public response to warnings of impending disasters?" It is the purpose of the concluding part of this section to summarize and theorize about public response to warnings. We also comment on what these conclusions suggest for planners of emergency public warning systems.

5.4.1 The Nonbehavioral Aspects of Response

People respond to warnings through a social and psychological process; to comprehend warning response means to understand that process. Planning for a sound public response to a possible future emergency means that this social and psychological process must be addressed.

The process follows: (1)the odds of good public response are enhanced if warnings are personalized by those who should personalize them and not personalized by those who are not at risk; (2)the probability of effective warning personalization increases as a direct function of the level of belief elicited by emergency warnings; (3) belief in emergency warnings can have its best effect on personalization if it is preceded by accurate public understanding of what is being said in a warning; and (4)understanding the contents of a warning presumes that warnings are heard by the public.

Our first general conclusion, therefore, is that public warning response is best understood, and planned for if it is viewed as a series of related sequential factors which are hearing warnings, understanding what is said, believing what is heard, personalizing what is believed as may be appropriate, and then engaging in response behavior. Of course, the process we outline does not always function this way in the real world. For example, it is possible in any evacuation to find evacuees who did not personalize a warning, did not believe that the disaster would impact the area, or even did not understand what was going on. Consider a teenager who evacuated only because it was a chance to cut school and party with friends in another town or the older woman who evacuated only because her daughter insisted that she do so. Usually, however, the process we outline above will help explain most of the behavior that occurs in response to warnings.

5.4.2 Response Process Determinants: An Overview of What Is Known and Its Implications

In an endangered population, random chance does not determine who does and does not hear, understand, believe, personalize, and respond to emergency warnings. These sequential steps in the warning response process are the consequences of the effects of the factors that we have already grouped together into the categories of receiver and sender determinants. The following general conclusions we are able to reach regarding these factors are based on our review of the empirical record.

First, different members of a population belong to different communication networks and have access to different communication linkages to the outside world. Consequently, the number of people who hear a warning can be maximized by disseminating warning messages over the full range of public communication networks.

Second, the understand-believe-personalize-respond stages of the response process all appear to be facilitated by providing emergency information that is both convincing and reasonable from the public's point of view. The empirical record documents well what does and does not constitute reasonable and convincing emergency warning information from the public's viewpoint. As we have already seen, warnings are perceived by the public to be convincing and reasonable if they are specific, consistent, accurate, certain, and clear as to the location of the area of risk, guidance about what the public should do, the character of the hazard, and the amount of time until its impact. Changes in the content of warnings that would make them appear inconsistent with other warnings should be explained; uncertainty regarding, for example, the

probability of impact, should be explained, and why the public should act upon uncertain information as if it were certain should also be explained. Warnings should also be repeated frequently; it is insufficient to issue a warning once or so infrequently as not to provide the public a chance to hear the warning multiple times. Additionally, warnings are most effective if they come from a source that maximizes the credibility of the warning information. Who is credible for one person, however, may not be a credible source for another. Credibility can also change over time. Therefore, it seems important that warnings stem from a mix of sources or a panel. This panel could include, for example, scientists, officials, a familiar local personality, and a familiar disaster response group such as the Red Cross. Credibility of warning information is also enhanced by the confirmation process and the frequency with which a particular warning message is heard.

Third, even when warnings meet all these standards they cannot produce convincing and reasonable emergency information for each and every member of a public. People have inherently different perceptions of fact and circumstance which they bring to an emergency warning response setting, and which almost predispose them to different responses. In fact, different researchers have found a multitude of factors that correlate with variation in warning process outcomes, including age, sex, length of community residence, locus of control, experience, proximity to impact area, education, environmental cues, seeing neighbors evacuating, and stress, to name but a few. But these factors, in our view, are a multitude of different indicators of the same more general concepts, and these general concepts provide an avenue for understanding how public differences of fact and circumstance can predispose variation in warning response.

Four concepts can explain and organize the empirical record regarding the effect of receiver determinants on warning response process outcomes. These are (1) variation in the ability to process risk information; (2) access to social and physical networks and events that would facilitate desirable warning response process outcomes; (3) incentives to be vigilant, take a warning seriously, or err on the side of caution; and (4) constraints to desirable warning response process outcomes.

People vary in their ability to process the risk information contained in a warning of an impending disaster. Variability exists because of differences between people, such as level of education, cognitive abilities, pre-emergency knowledge about a particular hazard, experience or lack of it with a particular hazard, and the degree of fatalism with which they approach life. Variability also exists because of situational circumstances characterizing a warning event. It is easier for people to impute meaning to risk information when their environment provides cues supporting the content of the warning information, for example, heavy rain in the context of flood warnings, sirens in the event of an invisible radiological emergency, and seeing neighbors evacuating or patrol cars issuing warnings as people contemplate whether or not they are at risk. Human variation in the ability to process risk information, for both factual or circumstantial reasons, can lead to variation in warning response.

People also differ in terms of the access they have to social and geographical networks and events. These differences can also lead to differences in warning response process outcomes. A range of social-network attributes can make a difference in response process outcomes. For example, persons who are part of large and well-established social networks and friendship groups are more likely to receive informal warnings. Consequently, they are more likely to confirm warnings, as well as understand, believe, and personalize warnings, and engage in response. Social-network membership also enhances the odds that people have someone to talk

to as they seek to define the warning situation and arrive at a meaning for it. Network membership also increases options for warning response—for example, having the home of a friend or relative to evacuate to, or receiving an invitation to do so. Persons who are not at home when they receive a warning are denied at least partial access to their networks and have a lower probability of responding appropriately.

Geographical proximity to the area at risk can also affect process outcomes. The further away one is from the area, the more distorted the emergency information one has access to and the less informed the warning response decisions. Human variation in network access, either by permanent or circumstantial differences, will lead to variation in warning response process outcomes.

People who receive warnings also differ in terms of factors which act either as incentives or as constraints to sound responses. Some people have more of an incentive to be vigilant, take a warning seriously, investigate what is happening and confirm a warning, or to err on the side of caution. Others simply lack some or all of these incentives. Incentives can exist for a variety of reasons, such as being in a role of responsibility for children, being socialized into a protective or nurturing role like that of a parent, or being predisposed to perceive risk in one way or another as regards a particular hazard. Incentives can also be circumstantial—for example, having only a very short time until impact and not being afforded the luxury of being able to socially negotiate the meaning of a warning.

Some people, again by virtue of factual or circumstantial differences, can be constrained from sound warning understanding, belief, personalization, and response. Constraints include lacking the resources necessary to act (not having a car in which to evacuate), being unable to engage in some actions for physiological reasons, belonging to an ethnic group which sometimes distrusts the information that comes from the mainstream, being of a psychological state that precludes sound judgment (being particularly stressed, being elderly enough to not be open to the occurrence of low-probability disastrous events, ascribing to unfounded fears like the fear of looting), or simply being unwilling to engage in any action until assured of the safety of a loved one or other intimates.

In conclusion, receiver characteristics vary widely among members of a public in any one warning circumstance, as well as between different events. In warning events that provide convincing and reasonable emergency warning information to the public, the understanding, belief, personalization, and response of the public can be sound. The effect of receiver determinants on warning process outcomes are not unchangeable laws of nature. It is possible to design a warning system with sender characteristics that maximize the probability of sound public response, and it is also possible to minimize the negative impacts of receiver characteristics. These goals can be achieved by a range of planning alternatives, with the specific planning elements to achieve the goals varying from hazard to hazard and across entities. The basic principles and planning goals, however, should be the same across hazards and planning entities.

5.4.3 The Confirmation Process

Our third major conclusion regarding public response to warnings is that confirmation of warnings underlies the entire warning response process. The notion is straightforward and important. Regardless of the widespread popular myths in American society to the contrary, people are a hearty lot and are not easily convinced that the unthinkable (a disaster) can happen. Many public emergency managers are willing to express concern that the public will panic when

faced with news of an impending catastrophe. Many others presume that issuing a warning will immediately be followed by prudent public action in response to hearing the message. Still others speculate on the basis of misinterpreted evidence that warnings for some types of impending disaster will elicit dramatic and immediate public flight (e.g., fleeing American cities on the heels of initial notifications of an impending nuclear attack or a radiological emergency at a nuclear power plant).

In fact, the accumulated evidence strongly suggests that the first response (and perhaps even the second and third response) of most people to receiving a warning message is to seek to confirm that message, to get more information, to talk over the warning with others, and to hear the same message again. Confirmation of warning messages is necessary for most people before they act in ways that go beyond seeking confirmatory information.

The need to confirm warning information declines as a function of receiving well-planned warnings in the first place, for example, warnings that are specific and frequently repeated. Emergency planners would do well to recognize and provide for public warning confirmation rather than leave it to chance.

5.4.4 A General Model

The research record suggests a model, presumed to depict cause and effect, which summarizes the determinants and consequences of public response to warnings of impending disasters. Figure 5.3 is our attempt to construct such a model informed by the empirical record discussed earlier in this section and in Appendix B. The boxes in the model represent the factors which have already been discussed in detail, and the arrows represent cause and effect between the factors. It seems quite reasonable to conclude that the effect of receiver factors in the model can be reduced as the sender factors escalate in quality in any given emergency.

The model presented in Fig.5.3 is best viewed as one in need of future empirical test. It does well represent, and then hypothesize, the character of cause and effect suggested by the empirical record. It was, obviously, induced from the existing data. To the best of our knowledge no single research effort has sought to measure each factor or concept in the model systematically and analyze the entire system in a multivariate format. Therefore, although it is possible to hypothesize the model on the basis of empirical studies, it is impossible to conclude it to be scientific fact.

5.4.5 Specialized Topics

The substance of this section has been focused upon response of the general public to warnings. We have not addressed specialized topics. It is the purpose of Sect.5.4.5 to review a few of the most important special topics and activities regarding public warnings.

5.4.5.1 Alerting Special Populations

Some segments of a population require special warnings simply by virtue of their unique character. These population segments include those in special facilities such as schools, prisons, old-age homes, hospitals, and other institutions. The warnings required by such institutions are probably not different from the sort provided the general public. However, it is likely that such facilities would require more time for warning response than would be required by members of

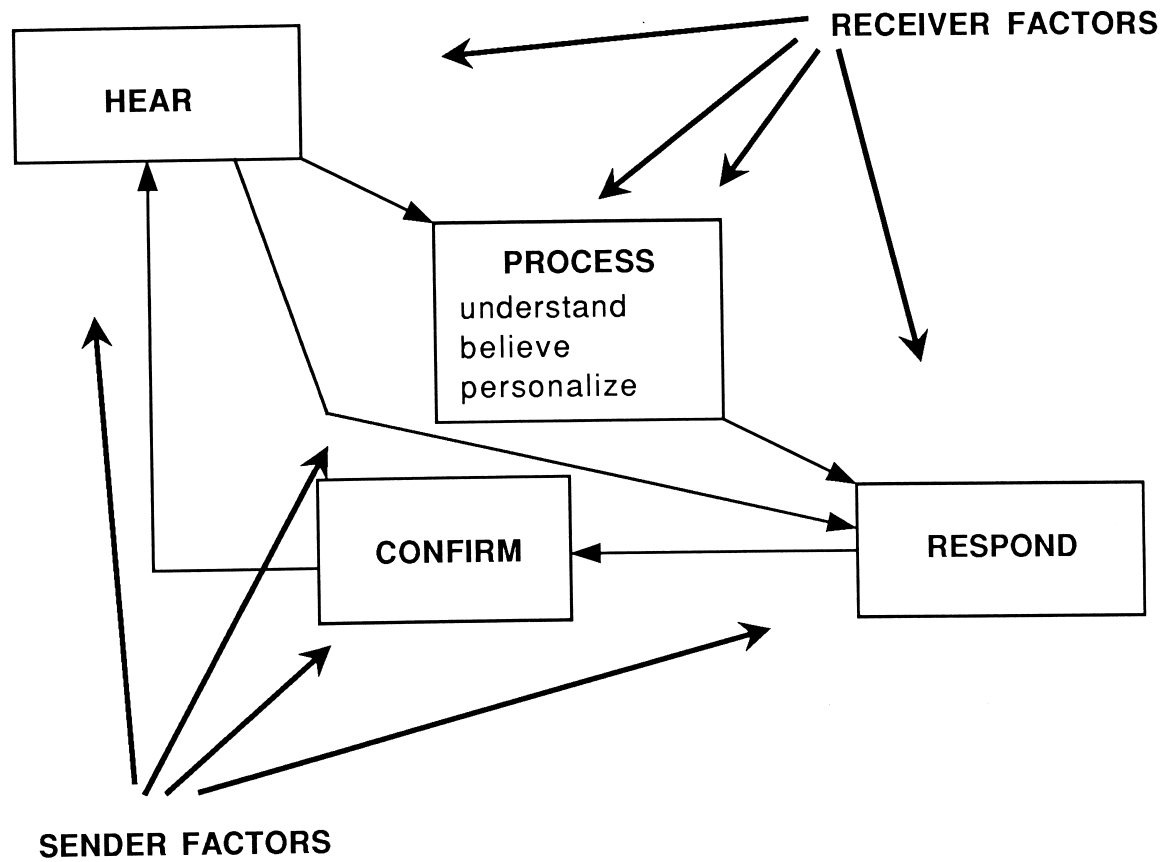


Fig. 5.3. A model for the determinants and consequences of public warning response.

the general public. Consequently, it would be useful if means were provided to specially communicate warnings to such facilities, as, for example, over tone-alert radios or dedicated phone lines.

Special populations with unique warning needs can also exist in noninstitutionalized settings. For example, the elderly may occupy a particular geographical region of town. Since older people require a larger effort to convince them to engage in protective actions such as evacuation, special warnings should be provided for their neighborhood (i.e., route notification or through the frequent repetition of media warnings).

5.4.5.2 Public Education

Research documents that pre-emergency knowledge in a public enhances response to warnings. This knowledge can be gained in a variety of ways, for example, through disaster experience. Research on pre-emergency hazards education which has examined the effect of brochures, mailers, and other educational devices has produced mixed results regarding effectiveness. Some studies do report a positive effect; other found the effect to be negative, while other studies found that pre-emergency education attempts had no effect. At present, there is inconsistent evidence that pre-emergency education has a positive affect on warning response. One should not interpret this to mean that education is not worthwhile. It is unclear if inconsistent findings result from poor design of educational efforts being studied or inadequate research methods. Nevertheless, we do know that knowledge regarding a hazard, appropriate protective actions in response to hazard warnings, and the character of existing warnings systems are the major topics which should be covered by public education.

5.4.5.3 Response Anomalies

There may always be response anomalies regardless of the quality of warnings issued to the public. For example, there may always be a few members of a public who simply refuse to engage in protective actions. The well-publicized case of Harry Truman during the eruption of Mount St. Helens is illustrative. Mr. Truman received warnings and believed that the volcano would erupt. He simply refused to evacuate. No warning system can be 100% effective because some few people may refuse to heed the advice in warnings regardless of their character. In a free society, there will never be a way to avoid response anomalies such as these.

5.4.6 An Application Goal

The 1989 Hurricane Hugo provides an example of the general application goal for using findings from public response research effectively. This was one of the largest storms to ever hit the United States. Several states and territories were impacted, and different populations engaged in different protective actions. For example, thousands of people evacuated, thousands of others sheltered in their homes, and thousands did nothing. For the most part, each different population made the correct response. It is likely that each did so based on accurate alternative perceptions of risk, and these were quite heterogeneous across the affected multistate area. The reason for this success was that a multitude of different warning messages were disseminated. In addition, these different messages were sufficiently targeted and detailed enough to help almost everyone accurately perceive their local risk, and then act accordingly. The warning system had been

refined by experience and it also incorporated findings from public response to warnings research. Consequently, few people lost their lives in a disaster that could have killed many if it occurred 25 years ago.

6. HAZARD-SPECIFIC ASPECTS OF WARNING SYSTEMS

6.1 HAZARDS TYPOLOGIES

A single generic warning system could be designed if all hazards had the same properties. This is obviously not the case. In fact, many attempts have been made to classify hazards into groups for a variety of purposes. For example, classification has been attempted with respect to causal agents (Burton and Kates 1964), energy release (Hewitt and Burton 1972; Haddon 1970), physical hazard characteristics (Burton, Kates, and White 1978; Quarantelli 1985), perceived hazard characteristics (Golant and Burton 1968; Slovic, Fischkoff, and Lichtenstein 1979), and multidimensional profiles (Hohenemser, Kates, and Slovic 1985).

None of these existing hazard typologies have been developed in reference to warning systems. It is our purpose in this chapter to develop a warning-specific hazard typology for geological, climatological, technological, and national security events. We then consider the implications of hazard classes for warning systems.

6.2 HAZARD CHARACTERISTICS

Six hazard properties have direct applicability for warning systems, and each property impacts upon one or a set of the three basic components of a warning system (the detection component, the emergency management component, and the public response component) as described in Sect.2. These six properties provide a framework for the description of hazards that will help address the issue of generalizing warning system principles across hazards. These factors are (1) predictability, which relates to the ability to predict or forecast the impact of a hazard with respect to magnitude, location, and timing; (2) detectability, or the ability to confirm the prediction that impacts are going to occur; (3) certainty, or the level of confidence that predictions and detection outcomes will be accurate or will not result in false alarms; (4) lead time, which is the amount of time between prediction/detection and the impact of the hazard; (5) duration of impact, or the amount of time between the beginning and ending of impacts in which warning information dissemination can occur; and (6) visibility, the degree to which the hazard physically manifest itself so that it can be seen or otherwise sensed. The following portions of this section discuss hazards in reference to these six relevant factors.

6.2.1 Hurricanes

The tracks of hurricanes are predicted at 72-, 48-, 24-, and 12-h time periods before expected landfall. Given current forecasting techniques, prediction of hurricane position, timing of landfall, and magnitude are not highly accurate. For example, at 48h, it is only possible to narrow the probable landfall position to a 600- to 700-mile stretch of coastline. At 24h, this area can be narrowed to about 300 miles, with an average time error of about 6h. At 12h, the position may be targeted to within 50miles of actual landfall. Hurricanes can change intensity and direction fairly quickly, and these changes are not always predictable. Hurricanes are easily detected and tracked using existing satellite technology. Data are collected using specially instrumented aircraft which make periodic flights through the hurricane. Given the erratic behavior of most hurricanes, there is great uncertainty in their impact location, time, and

magnitude. If warnings are issued 24h before expected landfall for a 300-mile segment of the coast, about 80% of those warned that they may be in the path will not be seriously affected by the storm. Probabilities for landfall are issued for given segments of the coast to attempt to reflect the uncertainty of the landfall. Hurricanes vary in duration. A typical warning period may last for 3d, but a stall may extend that period another 72h. Reentry is usually possible 24 to 48h after landfall. Hurricanes are visually announced by rough seas and increased wave action, but often these signs appear too late to affect warning response. Television use of radar and satellite imagery provides good visual representations of the hurricane location.

6.2.2 Tornadoes

General weather conditions that may lead to the formation of a tornado are fairly well understood, and they can be forecast, but prediction of the formation of a specific tornado on the basis of meteorological conditions is not feasible. Once a tornado has formed, little can be done to accurately predict its path or where it will cause damage, although the general direction can be estimated. Tornadoes can be detected and tracked using Doppler radar or by visual observation. Conventional radar is of limited use in detecting tornadoes. Because the precise track and level of damage caused by a specific tornado is subject to uncertainty, a large area must be warned even though the probability that any given site will be affected is small. Forecasts of conditions that may result in tornadoes are issued daily with frequent updates. Warning of a specific tornado depends on sighting and may come minutes to perhaps an hour before impact. Funnel clouds may be seen under some conditions, but at other times darkness and rain obscure the funnel. Individual tornadoes are of very short duration, although the storm spawning them may last for hours.

6.2.3 Flash Floods

The distinction between flash floods and riverine floods is that the former have a short amount of time between precipitation and flooding (usually defined as less than 12h). Flash floods typically occur in western states and involve streams and rivers with low-volume normal flows. However, they can occur any place where heavy rains fall during short periods of time and runoff channels cannot contain the flow. Flash floods are difficult to predict because of the short lead time between the rainfall and flooding. NWS issues daily predictions of flash flood conditions based on estimates of available moisture for precipitation. Prediction of the specific watershed in which a flood might occur is not feasible, and prediction of the magnitude or timing of a flood is not well developed. Areas subject to potential floods are usually well known before the event; maps of known floodplains produced by the National Flood Insurance Program have been disseminated to local emergency officials. When flooding occurs, the impact area is defined by the extent of flood waters, although the hazardousness of the flood is not always defined. Flash floods are often difficult to detect because they are produced by intensive localized precipitation but can be detected if instruments such as precipitation gauges and stream-flow monitors are in place and can be observed on short notice. Flash floods, by definition, have short lead times ranging from almost zero warning time to as much as 12h. The flooding itself is usually of short duration, and flood conditions rarely last for more than 24h, with waters receding rapidly. Flooding conditions are easily recognized, particularly in dry streambeds. Water depths and velocities are sometimes difficult to interpret visually.

6.2.4 Riverine Floods

Riverine floods are differentiated from flash floods because of their different characteristics and geographical distribution. Riverine flooding occurs on major river systems such as the Mississippi and is characterized by slowly rising waters. Flooding occurs when the water levels exceed the flood height or stage of the river system and overflow the banks. Hydrological and meteorological data are used in mathematical simulation models to predict riverine flooding. Forecasts are made for flood seasons based on seasonal precipitation and long-range weather forecasts. Potential flood events are forecast using rainfall data and hydrologic information in run-off models. Impacts are largely determined by the depth of floodwaters and also the speed of flow. While prediction of the precise locations in which flooding will occur is not feasible; the general areas of potential risk are usually well defined, and prediction of the timing of the flood is reasonably accurate. Riverine flooding is readily detectable using stream height monitors which record the progression of the flood towards its crest at various stream reaches. Flooding occurs when the bank height is exceeded by the river height. Riverine flooding due to the breach of a flood-protection device such as a flood wall or levee is more difficult to monitor. Flooding in this case is detected by visual means. Riverine floods are, by definition, of slow onset, and larger river systems and downstream reaches usually have longer lead times. Current forecasting techniques give as much as a week of lead time may occur on major river systems, and most riverine floods will be detected at least 12h before flood crests occur. Riverine floods are often of relatively long duration; it is not unusual for flooding to last from several days to as much as a week before waters subside. Flooding is easily seen, and the depth of the floodwater is usually determinable because it rises slowly and can be measured with familiar references such as buildings or light poles.

6.2.5 Avalanches

There are three categories of avalanches for the purpose of prediction: direct-action, delayed-action, and wet. General conditions for all types of avalanches are understood and allow a prediction of when avalanches are likely. Direct-action avalanche conditions are forecast using meteorological snowfall models. The other two types involve snow stress factors and are more difficult to forecast. Predictability varies by size of forecast area. Fairly specific predictions can be issued for small areas such as ski resorts when data are abundant and field observations possible. Forecasts for larger areas depend mainly on general weather and snow conditions. Specific avalanche detections require field observation of conditions or possibly instrument readings on snow-pack stress. Zone of impacts are sometimes known from previous activity. Detection of release is made primarily by visual observation, and little warning is possible after release. Even under warning conditions, it is difficult to know when and where an avalanche will occur. Potential avalanche areas are visible to trained observers, and avalanches can be visually sighted following release in open areas but not in forested areas. Sound may also provide warnings.

6.2.6 Tsunamis

There are two categories of tsunami events: distant and local events. Distant tsunamis travel over large distances of open waters. Local tsunamis are generated immediately offshore from the impact area. No current means exist to predict whether a seismic activity will generate a tsunami. Once a tsunami is detected, general landfall times and locations can be predicted, but actual impacts (run-up heights) to given coastal locations cannot be predicted. Risk zones are largely known for some locations, but not for others where mapping programs have not been conducted.

Both distant and local tsunamis are detectable using seismographs and tide-monitoring stations. Little uncertainty exists in detecting distant tsunamis in areas that are instrumented and detection is on the side of caution. Greater uncertainties exist for local manifestation of tsunami run-up. Seismic monitors used to detect a local tsunami create great uncertainties and may prove to be correct in only one case in ten on average. Lead times for warnings vary with location for distant tsunamis, but range between 4 and 15h. Very short lead times can be expected for a local tsunami. Impacts will usually consist of multiple waves spaced over intervals ranging from minutes to hours. The onset of a tsunami will usually be marked by a drop in the sea level, although in other cases the sea level may rise. Usually the first wave is smaller than the next several and is a signal of further larger waves.

6.2.7 Volcanoes

Predictability of volcanic activity varies according to location, type of activity, and level of instrumentation. Long-range forecasts are issued by USGS, but no empirical record has been established to validate their accuracy. Short-term forecasts of eruptions are feasible in some circumstances. Eruption activity is detectable through instruments, but actual manifestation of volcanic hazard effects requires visual reporting. Long-term warnings may provide vulnerable locations with years of advance notification. Short-term warnings may give several days to several hours of warning. Other eruptions may occur without warning, and once an eruption has occurred, different volcanic hazards (ash, pyroclastic flow, blast, mudflow, avalanche) will have differing lead times depending on local conditions and the nature of the eruption. Such lead times may range from minutes to hours following the eruption. The zone of impact for each hazard can be identified prior to eruption through extensive study. The duration of eruptions may range considerably, from days to years. An eruption is readily visualized; however, visual confirmation of an eruption may be too late for effective response to the warning.

6.2.8 Earthquakes

Long-term earthquake prediction has not been firmly established as a feasible practice. The record for prediction has been variable worldwide, but no destructive earthquakes have been predicted in the United States. Currently, one prediction exists for the Parkfield region in California. An earthquake is readily detected by seismographs; however, this is too late for warning of the direct hazard. Warnings may be needed for secondary hazards and subsequent aftershocks. An earthquake prediction has five components—lead time, time window of impact, expected magnitude, geographical area, and probability. The length of the lead time for earthquake warnings is extremely variable, as is the time window. Some potential exists for

short-term (less than 2-d) predictions in areas with instrumentation. In other situations, a prediction may evolve into a warning that is more appropriately cast as long-term earthquake potential. Main shocks last for less than 1min; aftershocks and secondary hazards may persist for weeks or months. No visual clues of an event occur until the event, although some people believe that unusual animal behavior is a sign of an impending earthquake.

6.2.9 Landslides

Landslides can be predicted with respect to magnitude, location, and time only in a few areas that have undergone detailed geological and engineering studies. In a few cases, impacts can be defined with reasonable certainty. By and large, however, most landslide areas of the nation are classified as generally susceptible to the hazard without more specific warnings. Landslides impact almost instantaneously; they can be prefaced by visual ground failure and cracking for days or weeks before impact. In these circumstances, warning lead times can be long and fall into one of three USGS warning categories: a degree of risk greater than normal, a hazardous condition, and a threat that warrants public response consideration.

6.2.10 Dam Failure

Susceptibility of dams to failure has been broadly established by dam inspection programs, but the ability to make specific predictions of failure under various failure modes is not well advanced. Once failure occurs, flood hydrographs for various breach conditions can be used to predict the timing and degree of downstream hazards. Failure can be detected through sensors or by visual observation. Uncertainty comes from the inability to predict the timing and extent of dam failure once conditions for a potential failure are identified. A second source of uncertainty concerns the amount of water that may be released once failure occurs. Lead times for warning may range from near zero in a case where no detection occurs to many hours for downstream locations. In some cases advance warning of potential failure may occur many days beforehand. Flooding produced by dam failure is easily recognized, particularly in dry streambeds. Lead times to inundation downstream depends on the water velocity and distance. Water depths and velocities are sometimes difficult to interpret visually. Areas of potential hazards can be defined before the failure.

6.2.11 Transported Hazardous Materials

Prediction of hazardous materials transport accidents is practically nonexistent, though some locations may be identifiably hazardous based on historical records. Once an accident is detected, abilities to predict downwind hazards are relatively crude, since some releases of materials are detectable only from visual observation or odor. Great problems exist in determining the type of material and quantities involved (because of errors in cargo lists). Almost no lead time exists in some situations where releases are instantaneous; many hours or even days may exist in other events where no release occurs. Events may last from several hours to several weeks. Some visual evidence of spill or plume or secondary hazards such as fire may be present.

6.2.12 Fixed-Site Hazardous Materials

Capabilities to predict accidental releases of materials through monitoring devices are very poor and not well developed, although variability among industries and facilities is likely. Once such an incident is detected, downwind hazard prediction depends on the availability of data on source terms, knowledge of toxicity, and modeling capabilities. Technologies exist to detect major releases of most toxic materials, although equipment to do so may not be installed in many sites. Major uncertainties regarding possible scenarios, as well as the hazardousness of potential releases, create constraints to effective warnings. In most cases lead time between detection of a problem and impacts will range from 1 to 24h. Accidents with shorter lead times may also occur. Events may last from several hours to several days.

6.2.13 Nuclear Power Plants

Some capabilities exist to predict a nuclear power plant accident based on plant monitoring instruments although predictions are to some extent dependent on operator interpretation. Downwind hazard prediction is fairly advanced if source term data are available and accurate. Releases are detectable by radiation monitors and plume tracking capacities. Zones of impacts are largely confined to a 10-mile radius of a plant, but the location of actual impacts will depend on meteorological conditions. Some accident scenarios can present very uncertain plant conditions with ranges in possible degrees of off-site hazards. Given current accident scenarios, a minimum of 15 min of warning lead time to several days of uncertain conditions may exist. Events may last from less than an hour to perhaps a week.

6.2.14 Nuclear Attack

There is no proven method that can predict the outbreak of a all-out nuclear crisis or attack. The rough likelihood could be estimated on the basis of world events and actions producing the crisis. Specific attacks may be detectable through intelligence or monitoring of military positions; prediction of a strike, once under way, is possible using radar and satellite systems. Prediction in the former case could occur up to several weeks prior to the attack and in the latter case less than 15min before impact. A protracted crisis could last an indeterminate length of time—possibly a month or longer—creating a complex warning situation. High- and low-risk areas have been delineated for initial effects, but great uncertainties exist as to where and when impacts would occur. Limited nuclear attack by a minor nuclear power presents a highly uncertain situation as does the possibility of protracted nuclear war.

6.2.15 Terrorist Activities

There is no proven method for predicting a terrorist attack. Some people or locations may be more vulnerable or at elevated risk. An incident may be detectable through intelligence and monitoring of known terrorist groups. Detection may come from observation, from information released through the media, or from threats made against the object of the terrorism. The amount of time for warnings is extremely variable and is situation-specific. In some cases, several days of warning may be possible, while in others the warning may be immediate to the incident.

6.3 SPECIFYING HAZARD CHARACTERISTICS IN WARNING SYSTEMS

The previous brief descriptions provided some relevant information on the warning system relevant characteristics of hazards, and on variations in specific events within each hazard type. Variation across hazards in terms of predictability, detectability, uncertainty, lead time, impact duration, and observability suggests that some events are very dissimilar to others, while others are somewhat similar in terms of hazard characteristics that are relevant to consider in warning systems. This suggests that while a single type of warning system may not be possible, a unique warning system may not be needed for each hazard. In this section, we attempt to collapse hazards into groupings relevant to warning system design based on some general themes of hazard characteristics that emerge from the previous section. This assessment produced several types of generic warning systems with some similarities and differences across systems.

Any person in charge of warning the public of a potential hazard is faced with three major problems. First, is the hazard predictable or detectable enough, with a long enough lead time, to allow for the implementation of a public warning and protective response program? Second, how well known is the area and nature of the impact? Third, when the first impacts begin, how well can hazard impacts be detected? We can integrate the six factors used to characterize hazards in Sect.6.2 to address these three questions. The process of building a hazard characteristics warning system typology then resembles the decision tree presented in Fig.6.1. In some cases it will be clear that a given hazard falls neatly into one of the classes shown in the figure. In other cases, hazard subcategories (e.g., local versus distant tsunami) may fall into different classes. In yet other cases, a hazard may span two categories as time passes and its physical characteristics change (e.g., long-term earthquake potential versus a short-term prediction with a high probability).

To develop an initial typology of warning systems, we considered each of the hazard types in Sect.6.2 in turn, and then we addressed the three basic questions that are used to classify eight hazard types. Where ambiguity exists, we tried to discern why, and this led us to classify subgroups of hazards into multiple categories. The outcome of the initial classification is provided in Table 6.1. This exercise showed that hazards could be classified into six of the eight categories defined by the process. These classifications are useful for differentiating between types of warning system needed for various events and can be used for developing and planning warning systems for the right mix of anticipated events. The table is also useful in indicating how hazards overlap into multiple categories, suggesting that particular hazard types have shared and unique warning system needs. Finally, the classifications can help identify how the application of warning system technology and knowledge could shift a hazard into a different category of warnings.

6.3.1 Warning Systems for Long Prediction, Known Impacts and Easy to Detect Hazards

The first category of warning systems involves hazards that have long prediction times, have known types and areas of impact, and are easily detected before impact. This type of hazard presents the easiest warning situation. It typifies events such as slowly developing riverine floods, a Hawaiian-type volcanic eruption, a slowly developing dam failure, an ideal earthquake prediction, or a gradual nuclear power plant accident.

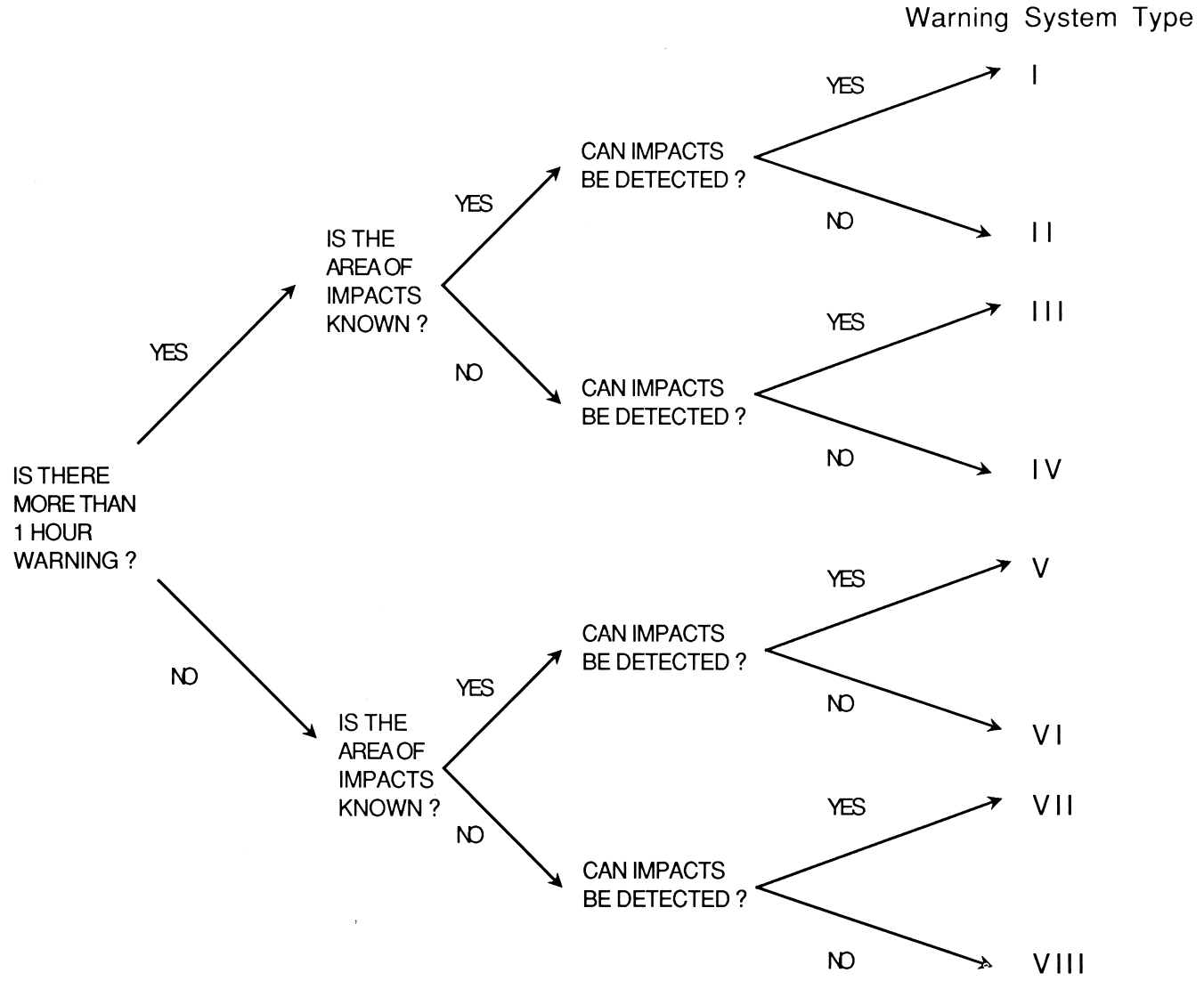


Fig. 6.1. Classification of warning systems.

Table 6.1. A typology of hazard types

Type and hazard category	Hazard
Type 1 (Long prediction time; known impacts; good detection)	
Meteorological	Riverine flood
Geological	Slow volcano; earthquake prediction
Technological	Slow dam failure; slow nuclear power accident
National security	None
Type 2 (Long prediction time; known impacts; poor detection)	
Meteorological	None
Geological	Earthquake prediction
Technological	Three Mile Island-type accident; slow fixed-site hazardous materials
National security	None
Type 3 (Long prediction time; unknown impacts; good detection)	
Meteorological	Hurricane
Geological	Distant tsunami
Technological	None
National security	None
Type 4 (Long prediction time; unknown impacts; poor detection)	
Meteorological	Drought
Geological	None
Technological	Hazardous materials threat
National security	Nuclear attack; protracted terrorist incident
Type 5 (Short prediction time; known impacts; good detection)	
Meteorological	None
Geological	None
Technological	None
National security	None

Table 6.1. A typology of hazard types (continued).

Type and hazard category	Hazard
Type 6 (Short prediction time; known impacts; poor detection)	
Meteorological	Flash flood
Geological	Fast volcano
Technological	Fast fixed-site hazardous materials
National security	None
Type 7 (Short prediction time; unknown impacts; good detection)	
Meteorological	None
Geological	None
Technological	None
National security	None
Type 8 (Short prediction time; unknown impacts; poor detection)	
Meteorological	Tornado; avalanche
Geological	Local tsunami; landslide
Technological	Hazardous material
National security	Nuclear attack; terrorist attack; sabotage

Sufficient time is available in these situations to put a plan into action and to devise a warning appropriate to the situation. Warning decisions can be made by group consensus and consultation across organizations. Different channels of communication can be used. A quick alert is not essential. Detailed and informative messages can be disseminated. Public response can be monitored, and the warning adjusted to take public response into account. In this type of situation, time allows for dissemination of all the relevant information people need to make an appropriate response.

6.3.2 Warning Systems for Long Prediction, Known Impacts and Difficult to Detect Hazards

This class of warnings applies to hazards with long prediction times, known areas, and known types of impacts, but without an easy recognition of threat or impact. A Three Mile Island-type accident, an imprecise earthquake prediction, or a slowly developing hazardous materials accident are characteristic of this type. They differ from Type 1 warning systems in that the onset of impacts is quick even though there is a long lead time.

As in Type 1 events, consensus decision-making is afforded by the long lead time; although the uncertainty associated with the threat may operate against full consensus. Unlike Type 1, however, a quick alert capability is needed, as is a quick means of giving information and instructions to the public. Messages must explain the basis for the uncertainty and cue people to respond if necessary. Ability to update information is needed. It is also desirable to monitor the public and control rumors. General education to enable people to understand the short-term uncertainty regarding the impacts would be desirable.

6.3.3 Warning Systems for Long Prediction, Unclear Impacts and Easy to Detect Hazards

Type 3 warnings are needed for hazards with long prediction times and good detection of impacts, but with uncertain area or types of impacts. Included are both hurricanes and distant tsunamis. These are events that are going to occur, but the time, place, and magnitude of the impacts are uncertain.

This type of warning requires centralized decision-making and management of information. It is not essential to have quick alert capabilities, as normal communication channels are sufficient to disseminate information. Messages must convey the uncertainty in a concise way and alert people to the need for precautionary response as well as the possibility that the warning may be a false alarm for many at potential risk. Frequent updates are needed, and confirmation of the existing conditions is important in portraying a clear picture. General education is useful to the warning but not essential.

6.3.4 Warning Systems for Long Prediction, Unclear Impacts and Difficult to Detect Hazards

This type of warning system is for events with long prediction times, but with both unclear impacts and poor detectability. This includes some hazardous materials threats such as a Love Canal-type situation, or a protracted terrorist incident.

Decision making is critical in these situations, and advanced planning is required to avoid unnecessary conflict. Consensus processes are also needed. Very controlled alert and information dissemination is valuable, and both normal and special channels of communication should be used. Monitoring of public response is probably necessary, and so are good mechanisms for rumor control and conflict resolution, as illustrated by the Love Canal and the Centralia, Pennsylvania coal mine underground fire incidents. Consistent updating of information is desirable. Pre-emergency education could help the warning system but is not essential.

6.3.5 Warning Systems for Short Prediction, Known Impacts and Easy to Detect Hazards

A Type 5 warning is characterized by a short lead time with known impacts and good means of detection. Currently there are no general categories of hazards that fit this warning type except on a limited basis. For example, some locations subject to flash flooding have automated warning detection systems that improve detection to the point that it fits this category instead of

Type 6. The same may be true of ski areas with avalanche detection capabilities and nuclear power plant and some chemical facilities with highly automated detection systems.

The characteristics of a Type 5 warning system resemble a Type 6. Decision structures need to be relatively automatic in these events. Little time exists for extensive consultation or consensus decision making. Pre-event decision criteria are usually needed. A quick alert is required, using a mix of communications channels. Specialized devices such as sirens may be used. Messages need to be predetermined and concise; the content and form of the warning must help to get people out of the endangered area or help them protect themselves in the known area of impacts. Pre-emergency education on adaptive responses could be useful to guide people to respond to alerts without detailed information.

6.3.6 Warning Systems for Short Prediction, Known Impacts and Difficult to Detect Hazards

A Type 6 system is for hazards with short prediction times, known areas and characteristics of impacts, but poor detectability. Here, less lead time may be available than for the Type 5 system. This is characteristic of many flash floods, a fast-moving volcano, or a fast-release fixed-site hazardous material incident.

Decision structures need to be highly automatic in these events. Little time exists for consultation or consensus decision-making. Quick alert is essential, using all available communications channels as well as specialized devices such as sirens. Messages need to be predetermined and concise, with content and form that clearly help to get people out of the endangered area, or help them protect themselves in the known area of impacts. As a result, education on adaptive responses is critical.

6.3.7 Warning Systems for Short Prediction, Unclear Impacts Easy to Detect Hazards

A Type 7 system is geared to hazards with short prediction times, unknown areas and types of impacts, but good detectability. Currently no general class of hazard fits this description. As Doppler radar is developed as part of tornado warning systems, this category may become applicable. The precise location of impacts will be uncertain, but forecasters will be able to accurately detect the presence of a funnel. This type of warning system is similar to Type 8, but could provide more specific messages.

6.3.8 Warning Systems for Short Prediction, Unclear Impacts and Difficult to Detect Hazards

This warning system is for hazards with short prediction times that are not easily detected and have largely unknown impact areas and characteristics. This includes tornadoes, avalanches, local tsunamis, landslides, many hazardous materials releases, a nuclear attack, or many terrorist situations. These hazards are differentiated from those of Type 6 in that the area of risk is not usually well delineated. Type 8 hazards present the most difficult warning problems because of the short lead time and high uncertainty.

Again, decisions for warning must be automatic and preplanned so as not to waste warning time on decision making. A quick notification is needed because of the short amount

of lead time. Messages must contain adequate information about the situation and the uncertainties. Unlike hazards of Type 6, Type 8 hazards do not have predefined risk areas. Some prepared messages with fine-tuning capacities are needed. Rapid updating of information is needed as the threat situation unfolds. Lack of time does not allow for monitoring or rumor control, although some is desirable. The warning system would benefit from pre-emergency education on how to get more information, how to respond correctly, and how to understand the uncertainty associated with the events.

6.4 REFINING A GENERIC WARNING SYSTEM TYPE

The warning system types presented in the last section of this chapter extend current ideas about the conceptualization and design of warning systems. One warning system design is simply not applicable to all situations. Our generation of eight warning system types itself ignores other factors also important in planning and implementing a warning system. Such factors include planning warnings for very sudden events (less than 15min lead time), dealing with events with very long lead times (greater than 2d), dealing with large-scale versus small-scale area events, dealing with events with the potential for massive impacts, dealing with concurrent hazards, and dealing with the differing or unique geographical or demographic characteristics of the warning area. Other factors may be critical as well, and should be defined as part of the planning process. Some of these additional factors and the inherent problems that they can present for warning systems are discussed in the following sections.

6.4.1 Sudden Events

Some events are of such rapid onset that warnings are extremely difficult, even with an appropriate warning system. These events materialize in less than 15 to 30min from the time of first prediction and detection. The general principles for the design of such warning systems are discussed under Types 5–8 warning systems. The shorter lead times require greater efficiencies and better execution of the warning function. It is not impossible to send out warnings within these shorter time frames using existing knowledge and technology; however, it may be expensive and require a higher level of planning.

6.4.2 Protracted Events

Some warning situations may extend beyond the period of time that people would normally remain vigilant, concerned, or even interested. Such situations require planning regarding the type of timing of information dissemination that will elevate public attention commensurate with the developing risks. For example, when a hurricane suddenly stalls and a 24-h advanced warning period expands to 72 h, it will be more difficult to capture the attention of people if an evacuation is needed.

6.4.3 Size of Impact Zone

Another relevant characteristic of hazard to include in the conceptualization of a warning system is the size of the potential impact area and the zone of actual impact in contrast to the potential area at risk. Warnings for events confined to fairly small areas are easier to engineer

than warnings for widespread areas. This is particularly true if the zone of impact extends over political boundaries with differing decision-making or warning responsibilities, which in careful coordination is needed to ensure a consistent warning effort. However, a warning may be needed over a wide geographical area even though the impacts will occur in a very localized area. This requires, if feasible, gradually narrowing the scope of the warning to the appropriate area as the hazard develops.

6.4.4 Massive and Rare Events

At times, an impending event may go far beyond what has been historically experienced or planned. A nuclear attack or a great earthquake would pose unique problems for emergency officials, because it may be difficult for warnings to encourage appropriate public protective actions. It is currently difficult to make precise recommendations on effective ways for dealing with such situations. Current efforts at public education are obviously different from emergency warnings.

6.4.5 Concurrent Hazards

On occasion, two events may occur either simultaneously or in sequence, both requiring warnings. This was the case of the 1985 Cheyenne, Wyoming, storm which produced both a tornado and a flash flood, events requiring differing protective actions. Little planning or research has been done to provide guidelines for dealing with these situations.

6.4.6 Unique Geographical Features

The physical characteristics of some locations—isolated canyons, suburbs with irregular road patterns, broad, featureless plains, and bodies of water—can make warning difficult and create problems in designing an appropriate warning system. Such characteristics require consideration in the planning process.

6.5 SUMMARY

In this chapter, we have attempted to explore systematically the relationship between hazard characteristics and warning system design. We have demonstrated that one design is not appropriate for all warning circumstances. Eight theoretically derived warning systems have been suggested; evidence suggests that it is possible to develop six alternative warning system types for use with differing hazards and hazard circumstances. Case studies of warning experiences reveal that using a warning system created for one type of hazard for a different situation may create problems that can lead to a warning failure. Finally, we have noted that other factors regarding the physical characteristics of hazards need to be considered in the design of any warning system. By integrating the organizational, public and hazard elements that we have presented thus far, it is possible to develop a sound set of warning principles. Planners can develop a sound warning system by integrating the organizational, public and hazard elements of warning systems.

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7. PROBLEMS, LIMITS, AND IMPROVEMENTS

The purpose of Sect.7 is to review a variety of issues that constrain an ideal warning system. Some of these issues are practical issues, while others are ethical; some are based on the research record while others are not. In addition, the section recommends more research with high potential payoff in knowledge and applications. Section7 concludes with reminder of recurring themes that have emerged from this review; these are presented as a philosophy of warning.

7.1 TECHNOLOGICAL ISSUES

7.1.1 Monitoring and Detection

The ability of a system to provide timely public warnings begins with monitoring the environment so as to detect hazards. Table7.1 summarizes the current state of development and applications of monitoring and detection technology in the United States.

Detection technology is readily available for some hazards and in a state of development for others. Technological capabilities also vary with respect to the amount of lead time provided and the "noise" in the detection signal. Monitoring technologies are of equal importance. Whereas detection refers to the recognition of a hazardous event, monitors provide ongoing data about the physical system. Coverage of monitoring technology is fairly good for some hazards and poor for others, such as hazardous materials accidents. Complete coverage of the entire U.S. land mass, or even of all areas where people live, has not been perfectly achieved for any hazard. The best coverages are for a massive nuclear strike and for earthquake aftershocks.

7.1.2 Communication Hardware and Use

Despite advances in technology, many warning systems are constrained by communications equipment problems. Recent problems (Sects.2 and 4) have included lack of equipment, equipment failure, lack of back-up equipment, and human error in the use of equipment. Problems with communications hardware surface at two levels: in communications between organizations and in the public notification process. These problems are only partially caused by lack of technology. Nevertheless, technological advancements (e.g., microwave relays or fiber optics communication lines) are still likely to improve future warning systems over today's systems. A greater problem is the lack of dissemination and adoption of technology among warning systems throughout the country. There is a reluctance by some to use innovative warning technology. Another problem is maintaining equipment so that it functions properly in an actual emergency. The warning systems that could benefit the most from adopting state-of-the-art communications hardware are those for which the technology could mean getting warning information to a larger number of people with greater reliability in a shorter amount of time at reduced per capita costs.

Table 7.1. Status of monitoring and detection technology and application coverage for warning systems

Hazard	Monitoring technology	Detection technology	Application coverage
Hurricane	Well developed	Well developed	Good
Flash flood	Well developed	Well developed	Partial
Riverine flood	Well developed	Well developed	Good
Tornado	Developed	Difficult	Good
Avalanche	Developed	Difficult	Poor
Earthquake	Developing	Difficult	Poor
Tsunami	Developed	Problems	Good
Landslide	Developed	Problems	Poor
Volcano	Developed	Problems	Poor
Dam failure	Developing	Problems	Poor
Transported hazardous materials	Poor	Difficult	Good
Fixed-site hazardous materials	Developing	Poor/Good	Poor/Good
Nuclear power	Developed	Developed	Complete
Terrorism	Developed	Problems	Good/Poor
Nuclear attack	Developed	Developed	Good

7.2 ORGANIZATIONAL ISSUES

7.2.1 Domain Conflicts

Conflicts among organizations over roles and responsibilities in warning systems are still problematic in some situations (see Sect. 4). The problem of organizational conflict goes beyond the realm of emergency management. It is symptomatic of organizational systems in general and may never be totally eliminated. However, there is evidence that the emergency planning experience may facilitate cohesion among warning system participants and that improved planning could help to minimize conflicts. Emergency planning for warning systems should address organizational domain negotiation as part of the planning process.

7.2.2 Decision Making

Normative decision tools are gradually being developed to aid officials in making warning decisions. These tools range from simple classifications schemes to complex computer simulation models. As these tools become more sophisticated and widespread, it will be important to monitor how they are used and to determine if they lead to better warning decisions. Complex or conflict-ridden decisions delay the issuance of public warnings (see Sect. 4). This is of little consequence in precautionary situations or protracted emergencies. In fast-moving events, however, decision-making problems may lead to ineffective warning or to delays. Ways of achieving more automated decisions in

the case of fast-moving events and hazards need to be explored and tested; these include computer recognition of tornadoes in Doppler radar data, expert systems for chemical plant accidents and automated public warning systems for earthquake events seconds away on other fault segments.

7.2.3 Maintaining a Warning System

Warning systems, except perhaps for those in place for nuclear power plant accidents, are infrequently put to a real or even a practice test. This problem of nonuse diminishes as the size of the area and the number of hazards served by the system increases, because such systems are more frequently used. It is difficult to garner support and finances for a warning system with low probability of being activated in any given year. Additionally, it is difficult to maintain an effective warning capability when a warning system is not used or tested. People who are a part of the warning process lose interest and shift their attention to more pressing day-to-day responsibilities.

Most warning plans are not reviewed or updated. Communications among participating organizations may wane with time. Personnel with time dedicated to the warning function may grow bored. We know of one warning plan, for example, which calls for meteorological experts to work on a 24-h basis to predict a potential downwind chemical release from a plant that has an estimated 1 in 1000 probability of a release with public health consequences. All of these characteristics diminish the potential effectiveness of the warning system when implemented.

It seems apparent that warning systems must be exercised often to guarantee their effectiveness (Sect.4). Frequent exercises occur for some hazards, for example for nuclear attack, but not for others. An alternative could be to build warning systems on top of existing communication systems that function routinely for other reasons. This could be difficult because many of the organizational and individual actors in most warning systems are brought together in unique configurations relevant only for the warning system. A good approach may be to construct warning systems on top of whatever routine communication patterns do exist and to exercise those systems often.

7.2.4 Recommending Protective Actions

The success of any warning system is dependent on recommending appropriate protective actions to the public and on the public's acting on those recommendations. Ambiguity in warnings about what the public should do has often resulted in needless loss of life in emergencies (Sect.5). Death and injury still occur in circumstances in which people thought they were doing the correct thing but were behaving inappropriately. This issue poses a major warning dilemma because not every emergency situation has a best protective action strategy. Many situations will have multiple protective actions that are appropriate for differing public circumstances; variations in protective response are difficult to communicate through warning messages.

A major factor that hampers providing good recommendations for protective actions is a poor understanding for some hazardous events of the effectiveness of each feasible protective action, and under what circumstances that effectiveness may be hampered or enhanced. For example, some uncertainties exist about sheltering versus evacuation. In hurricanes should people seek shelter or evacuate? In nuclear attack, is relocation more effective than sheltering from

fallout and blast? In earthquake aftershocks should people run outdoors in clear fields or seek shelter in an available structure? Emergency officials would benefit from clearer guidelines on protective action decisions for the range of hazards. The same is also true for the range of subpopulations at risk to whom they must issue guidance.

7.3 SOCIETAL ISSUES

7.3.1 Ethics and Warning Systems

Warning systems are meant to serve the public good by saving lives, property and reducing injuries. To do so warning systems must intervene into human lives and influence and guide public behavior. On the one hand warning systems should not interfere with civil liberties. On the other hand, they cannot help but do so to some degree.

Debates on ethical issues have surfaced from time to time regarding various aspects of warning systems. For example, in the early 1970s an effective alert device called DIDS (Disaster Information Dissemination System) was viewed as a warning breakthrough. This system externally activated radios and broadcast warning information. The system was not adopted because it was viewed by many as a breach of privacy. Today, however, tone-alert radios are in place in many areas for selected hazards.

Another frequently occurring ethical issue has been whether warnings should advise the public regarding protective actions or order those actions. Contemporary consensus is that warnings in the U.S. provide advice and recommendations. Sometimes this has meant standing by in the face of almost certain disaster as some decide not to evacuate and face almost certain death. For example, officials at Mount St. Helens knew that some residents refused to leave. Sometimes it has meant the opposite. For example, a week after the Rapid City flood, the mayor ordered another public evacuation, even though he lacked legal authority to do so. Ethical questions continue to surface on both sides of this matter. Such issues are not readily resolved, and resolutions are likely to vary across time and place.

7.3.2 Costs and Benefits of Warning Systems

Some hazards do not appear to warrant a large investment of money in warning preparedness since sufficient benefits in saved lives, reduced injuries and reduction in property loss would not justify warning system investment.

Two different approaches have been used in estimating the costs and benefits of warning systems. First, analysis can be performed on average annual losses. For example, this approach would compare the average annual costs for warning preparedness to the average number of lives saved by the system. In such an analysis the benefits reaped can appear low for disasters that occur infrequently. Second, analysis can ignore average annual estimates and instead focus on the potential for the infrequent catastrophe. For example, this approach would compare the cost of warning preparedness to the benefits of the system when the maximum credible disaster does occur. Most analyses of the costs and benefits of warning systems contain both of these approaches. Results can vary widely across hazards as well as for the same hazard in different communities.

Some decisions about warning system adoption and preparedness do rest on rational analysis of costs and benefits. Many times, however, preparedness decisions ignore this

approach or minimize its input to preparedness and systems are adopted even though they do not meet cost-benefit criteria. Warning systems often emerge because of policy decisions based on public sentiment after a particular emergency regardless of the outcome of cost-benefit analysis. Cost-benefit analysis versus political responsiveness after major emergencies are not necessarily compatible in the conclusions they might reach regarding the need for warning system preparedness. This does not diminish the need for including analysis of costs and benefits in making warning preparedness decisions.

7.3.3 Withholding Warnings

The control and timing of public warnings will continue to be thorny issues in emergency preparedness and response. There are several reasons why detectors and emergency managers withhold information.

First, there is an unfounded but widespread belief that the public will become unnecessarily alarmed if warned about a low-probability but high-consequence event. This belief has resulted in reluctance to tell the public about a hazard until it is absolutely necessary, and even then some warnings are delayed, muddled, or suppressed. This reluctance to inform has affected both hazard detectors and emergency managers. Examples concerning both natural hazards and technological can be found.

Second, warnings are sometimes withheld because of concern over negative social and economic effects on the hazard manager and on society in general. Only a partial disclosure of information may occur in such cases. This can seriously undermine warning effectiveness from the viewpoint of public protection. In such cases additional information may well become public through nonofficial sources, creating credibility problems for warning officials. Interestingly, withholding information in a warning situation can actually be the cause of the problem that it was originally designed to avoid.

The "to warn or not to warn" dilemma will continue to surface regarding the release of information about hazards to the public. Consider, for example, the dilemma facing a scientist with information that a whole town is likely to be destroyed from a volcanic eruption sometime during the next 20 years. To which vested interest does the geologist bow: those who think that the public has the right to know; those in the public who would probably not do anything differently if they did know; the shareholders of a property development corporation; the owners of the local tourist industry, who may not want to know; or the state emergency planning bureaucracy, which wants to know in order to do planning? The geologist would probably tell everyone. The dilemma of vested interests is likely to be strong in the future. Effective long-term warnings could well elicit the wrath of vested interest groups not served by the release of believable hazard information.

The "to warn or not to warn" dilemma also persists for short-term warnings and is not likely ever to be fully removed from warning systems. Most disasters cannot be predicted with total certainty. Officials must make decisions about whether or not to issue warnings on the basis of probabilities. For example, is a public warning issued if the probability of an earthquake is raised from 1% on any given day to 5% for tomorrow? If not, what percentage increase in probability must occur before a warning is issued, given that certainty, or 100% probability, will never be attainable? The dilemma is clouded even after a policy decision is made that a predetermined probability will trigger information flow to the public. At what probability of impact will the information being passed to the public cease to be hazard information and become

an actual public warning including recommended public protective actions? The forecasting of disasters before they happen is imprecise, and elaborate public warnings are needed to elicit good protective response. The dilemma of deciding at what level in the former is needed to activate the latter is not easily or readily resolved.

7.3.4 Liability

Liability can create problems in several ways. First, officials may fail to issue warnings to the public, and the event occurs. Second, they may warn the public, but the event does not occur. Third, they may provide a warning that contains wrong or inadequate information. Fourth, officials may withhold some relevant warning information from the public about an event that occurs. The consequences of each of these situations could be litigation involving the officials, the organization for which they work, or both.

We have been able to discover only a few documented cases in which fear of litigation actually constrained the issuance of public warnings. This lack of cases may be caused by the infrequency with which the topic has been studied. Nevertheless, there are two ways in which fear over liability can be minimized as a constraint to warning issuance. First, decision makers can be made free of liability for what they do or do not do in a warning situation. This has been accomplished through legislation for the governor of the state of California in reference to earthquake predictions. Second, warning decision makers can have their decision making formalized and subject to postevent audits; this is the case, for example, for parts of warning systems for accidents at nuclear power plants.

7.3.5 Public Response

Much is known about the process that shapes public response to emergency warnings (Sect.5). However, some problems still remain in fully understanding public response.

First, we do not fully understand how response can be enhanced by pre-emergency public information and education. It makes intuitive sense to educate people about hazards and possible future emergencies and warnings. However, the most cost-effective and salient form of pre-emergency warning education is not known.

Second, the factors which influence public warning response as described in Sect.5 may well differ in quantity as they occur in different emergencies. Nevertheless, these same factors are likely to operate in all emergencies to impact public response in the same theoretical way. Yet we do not fully understand with full mathematical precision the relative effect of all factors on warning response. Sorting out these differences, if they exist, would enhance our ability to develop generic multihazard and cross-hazard warning systems.

7.4 TOWARD IMPROVED WARNING SYSTEMS

7.4.1 Application of Existing Knowledge

A comparison of existing warning systems (Sect.1) with existing knowledge about preparedness leads to the conclusion that no contemporary system uses all that is known. Warning systems for nuclear power plant accidents are perhaps the most intensive users of preparedness knowledge. All warning systems could be improved in varying degrees through

review and adoption of existing knowledge. In Sect.3, we attempted to outline a framework for building better systems based on that knowledge.

Two key areas promise the most benefits in improving warning systems. These are building more effective organizational arrangements and improving the content and type of actual public messages. The former could remove some of the constraints that limit the dissemination of warnings in a timely fashion. The latter action could help increase the odds that the public will take appropriate and timely protective actions in response to warnings.

Some warning systems are relatively well designed; other systems can be greatly improved. Most fall somewhere between these extremes. We conclude that building generic systems and differentiating them on the mix of hazard types (as discussed in Sect.6) is a more effective way to upgrade warning systems than continuing with separate systems for each hazard. The generic warning process is similar for all hazards. However, the implementation of warnings can differ across hazards. These differences should be planned for when particular hazard and site characteristics are taken into account.

7.4.2 Needed Research

7.4.2.1 Differences and Commonalities in Warning Response

Warning response research has been varied in method and approach. Each piece of research has focused largely upon only one or some few of the many factors that affect response (see Sect.5). Consequently, research is needed which takes advantage of the knowledge already accumulated but which goes several methodological, theoretical, and practical steps further. An integrated warnings systems research effort is needed to (1)use state-of-the-art knowledge to study warning system structure and factors that influence human response; (2) measure those factors in the same or functionally equivalent way across a range of geological, technological, climatological, and national security emergencies to provide for sound cross-hazard comparability; (3)determine common themes applicable in all warning systems as well as hazard-specific lessons; and (4) allow research to be performed almost immediately after an emergency before warning response data become less reliable.

The specific purposes of cross-hazard comparisons should be (1)to determine common warning system elements for all hazards—for example, hardware and technologies, emergency organization, and warning messages; (2) to catalog what common warning system elements can be used to reduce duplication of warning systems in the United States and to integrate cross-hazard warning systems; (3) to suggest what common warning system preparedness elements are likely to hold in emergencies for hazards not yet experienced; (4)to reveal hazard-specific elements of warning systems needed for use in preparedness for the full range of potential hazards; and (5) to systematically test and refine a theory of public warning response. Something is already known about each of these issues, but knowledge is far from complete, and some of it is based only on anecdotal evidence which remains to be analytically demonstrated.

7.4.2.2 Adoption Constraints and Incentives

The state of knowledge regarding effective warning systems is good relative to other human interventions (land use, engineered solutions, insurance, etc.) to reduce losses from disaster. However, this knowledge is not fully used.

A research effort is warranted to determine the major incentives and constraints to adoption of warning system knowledge. This research should include all hazards for which warning systems could be useful. The research should also address the full range of entities that could be involved in adopting findings; these include local, state, and federal agencies as well as some private sector organizations that maintain warning systems. This research could do much to reveal why the high potential for setting up effective warning systems for most hazards is being ignored or is under used. It could also produce insights on how planners could be encouraged to use existing knowledge.

Finally, this research should include an assessment and cost-benefit analysis of existing warning systems to determine fruitful paths for cross-hazard integration of warning systems design and technology.

7.4.2.3 The Role of Public Education

It is unclear how and to what extent pre-emergency public education affects the behavior of people in response to future warnings. It is intuitive to presume that public education has a positive impact on public warning response. Moreover, it is not clear what type of public education is the most effective. At present, we can only hypothesize about the topics which pre-emergency public education should address, as well as about the form a public education campaign should take. For example, it would be appropriate to now hypothesize that the most effective form of public education is education that is a continuing process, specific in content regarding the actions which people should take, and varied in approaches used to deliver the information.

Research is needed to determine the relative effectiveness of alternative types of public information and education on warning response. This research should include the range of education avenues (i.e., brochures, school curriculum, telephone-book pages, and public signs, to name but a few), and seek to determine when and why the provision of information actually does result in learning. Research should also study the range of topics that could be addressed in public education, including, for example, the hazard, appropriate protective responses, and emergency warning types and sources. The effort should discover whether differences exist on the basis of hazard types, experience, location, and so on. It is likely that the intensity of the public education effort would affect subsequent warning response. Consequently, this factor should be made to vary in the research design; this would probably require field experiments.

7.4.2.4 Quantitative Decision Research

Warning system organizations (Sects.2 and4) involve a complex sequential system of tasks, roles, and decisions and cut across a variety of organizational subdivisions, different organizations, varied political boundaries, and sometimes the public and private sectors. There is historical evidence that dilemmas and uncertainties at each level in these interorganizational systems have caused warning system failures. The research record on the organizational aspects of warning systems is not elaborate, particularly when compared to the rich literature on public response to warnings. Most existing organizational studies are focused on disaster response and not predisaster warnings. Most such studies are largely case histories of a single event and were not drafted in analytical ways.

Uncertainties have affected and continue to affect all system decisions that lead up to public warnings. Two research efforts are needed to produce knowledge that could help minimize the effects of uncertainties on timely warning system decision making. The first should investigate how uncertainties detract from sound decision making. The second should investigate aids that would assist in making decisions.

We also need several analytical case studies of natural, technological, and national security events, focusing on inter- and intra-organizational decision making leading up to public protective-action advisement decisions. Such studies should seek to document how uncertainties affect decision making at each point in the warning system, from the detection of a hazard through actual evacuation decisions. The research should also address why uncertainties arose and what could have helped reduce the negative effects of those uncertainties on decision making. A quick response would be needed to make this research sound. Investigations should begin as soon as possible after an emergency has occurred, if not during the emergency.

In addition, the role of decision-making aids such as expert decision-making systems should be investigated. Several studies appear promising. First, a set of laboratory studies should be conducted to determine how under similar scenarios different available decision-making models and aids might lead to different or similar warning system decisions. The results of this research should enable the fine-tuning of good models and aids, as well as the abandonment of the less useful ones.

Second, the adoption of the models and aids should be investigated across localities engaged in warning system decision making. An adoption-diffusion/transfer study could do much to enhance the use of good models and aids. Such a study would be particularly useful, for example, on hurricane decision making, since good new models have recently become available.

Finally, work should be performed to discover what kind of information, aids, and models could assist decision makers in making warning decisions. This research should be from the decision-maker or "user" viewpoint. For example, it should determine whether evacuation decision makers with recent experience feel that "real-time" traffic data would assist in decision making, and if so, how that system could best be designed for their use. Such a survey would be performed on decision makers for a variety of hazards with recent public warning experience.

7.4.2.5 Warnings for Fast-Moving Events

Fast-moving events pose unique public warning and response questions. We know too little about the unique needs for public warnings for such events to offer conclusions with confidence. No warning response study has been conducted on an event with less than 30-min response time. It has long been known that most members of the public seek confirmation of warnings before taking an action such as evacuation. Yet some emergencies are so fast-moving that seeking confirmation leads to increased losses. We also need to focus on the social psychology present during fast-moving events. This research should produce findings that would enable endangered publics to make quicker protective action decisions in response to fast-moving events. The existing empirical research record does not include many such events, for these have been historically infrequent (Sects.4 and 5).

Research into fast-moving events should be cross-hazard, including events like flash floods and chemical spills during train derailments and should seek to generate generic cross-hazard principles as well as unique hazard-specific findings. Particular attention should be paid to how pre-emergency education and disaster warnings could help the public perform alternative

protective actions to evacuation. For example, some chemical emergencies would not cost lives if people covered their noses and mouths with wet cloths and stayed indoors.

Effective public response to fast-moving events requires that the hazard be quickly detected and that the public be informed rapidly. Constraints may inhibit this process, and each should be researched. One of these constraints deals with the hardware of public alert. Research should address alternative schemes for alerting endangered publics: sirens, telephone systems, and the like. Second, in fast-moving events the processing of hazard information in the detection and management components of warning systems must be streamlined. Retrospective studies of recent events and studies of events as they occur could help uncover procedures that would help reduce the time needed to process risk information prior to the issuance of public warnings to the bare minimum. Third, technical research is needed for some hazards to determine what the risks of public exposure are. For example, it may not be clear what are the risk scenarios nor range or efficacy of alternative protective public actions regarding the immediate release of nerve agent or other chemicals. This information can assist planning. Finally, research on the efficacy of pre-emergency public education for special fast moving events could help reduce the time needed for public response. For example, the application of research findings in this arena could possibly reduce the time the public would ordinarily spend seeking confirmation of warning received.

7.4.2.6 Warnings for Concurrent Hazardous Events

A three-pronged research effort is needed to fill gaps in knowledge regarding warning system planning for concurrent hazardous events. We were unable to find any warning studies that addressed this type of warning (Sects.4 and 5).

First, physical science and statistical studies should be directed toward cross-hazard assessments to typologize probable concurrent hazards for linked hazards (one causes another) and for independent hazards (both coincidentally occur at the same time). This ranking would provide an informed basis on which to judge which concurrent events should be planned for and which are best ignored. This effort need not be elaborate, but a systematic assessment by an interdisciplinary team of experts is needed in order to inform planning for concurrent hazardous events.

Second, planning and response experts should share judgments to produce a systematic catalog of warning planning needs for concurrent hazards. This assessment should detail generic and unique issues specific to unique hazards or sets of concurrent hazards.

Finally, prototype plans should be developed in some localities that can be transferred to others. This "action research" component has already been shown to be effective with earthquake and earthquake prediction planning, among others. This three-step research process (based on physical science, planning and social science, and plan development) is sequential, is predicated on existing knowledge, and promises payoff.

7.4.2.7 Media Role in Warnings

In emergencies, key media actors often intervene between those who have accurate information and the public. The media are the gatekeepers of most public risk information and warnings. The use of an Emergency News Center helps standardize information and fully inform the media in emergencies. Despite the important role of the media in warning systems, however, few studies have ever been performed on the media. We have done too little to bring the media

into the warning system preparedness effort. Currently, one research effort concerning the media in disasters is under way at the Disaster Research Center at the University of Delaware.

It is appropriate to proceed with at least two studies of the media in reference to warning systems. First, it would be useful to gather data on how the media presents emergency information to the public during warnings. This study should assess media public information output from the viewpoint of factors demonstrated to have an impact on public response (i.e., frequency, clarity, consistency; see Sect.5). Such a study would provide information regarding the final communication link in warning systems between the media and the public. Second, it would be useful to explore the most effective way to inform the media of the factors important to keep in mind when performing a role in a warning system.

7.4.2.8 Improving Communications

Warning systems are communication systems linking a variety of organizational actors to each other and then to the public. Therefore they involve communication devices and systems. Some of these are technological, such as dedicated phone lines, sirens, radios, and tone-alert radios. Others are behavioral, such as informal notification. The effectiveness of a warning system is dependent on systems such as these that constitute the "hardware" of a warning system.

Few planning efforts for warning systems have taken stock of the full array of communication systems on which a warning system depends, considered back-up means of communication, or addressed updating communications technology (Sect.1). It would be appropriate to assess the alternative efficiency and effectiveness of available means of communicating and explore how adoption constraints could be removed.

7.4.3 Multihazard Warning Systems

The classification scheme developed in Sect.6 is a first step toward resolving the question of whether the nation should pursue a single cross-hazard warning system or multiple hazard-specific warning systems. A single cross-hazard warning system would imply one warning system in place to warning of any hazard. Multiple hazard-specific warning systems imply separate systems for each and every hazard that could impact a particular place. This analysis suggests that a single-system design will not work for all different hazards warning situations but that some events with similar characteristics may fit the same warning implementation strategy. In any case, hazard-specific knowledge must be incorporated into any general warning system. It may be that a tiered warning scheme, which is a warning system with some shared components across hazards but also some unique hazard-specific elements (Fig.7.1), is the best approach to warning system development. Any warning plan would address warning system organizational principles (Sects.2 and 4) and the basic public response process (Sect.5). This plan would then be specified or tiered into unique implementation procedures for each of the different hazard types that a community may need warnings for as grouped in Sect.6 (see Fig.6.1). Finally, unique hazard-specific information and site-specific conditions would be annexed onto the plan.

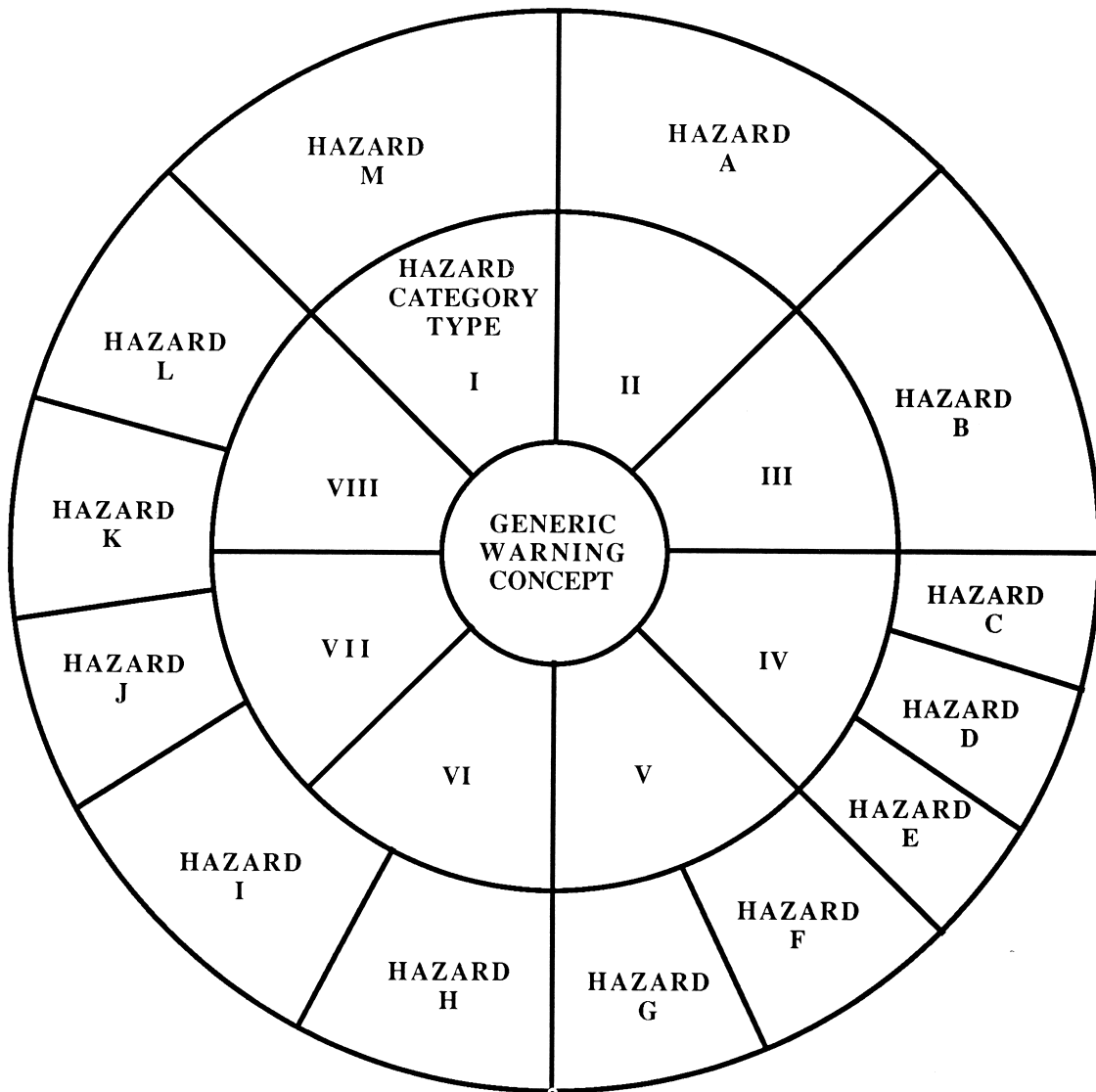


Fig. 7.1. A proposed cross-hazard tiered warning system scheme.

7.5 A PHILOSOPHY OF WARNING

Several recurring themes emerged from the review of warning systems research. These themes help frame some general principles for building warning systems.

7.5.1 The Role of Planning

History contains many examples of warnings that have been a success, but it also illustrates failures. Some of each type have not been prefaced by warning system planning. Interestingly then, emergency planning is not essential for an effective warning system in all cases. There are two reasons for this.

First, warnings are not rare events for some hazards in some parts of the country. For example, tornado warnings in some midwestern communities and flood warnings along the Mississippi are not uncommon. Repeated experience with warning events can teach those responsible for warning activities what does and what does not work. Plans are not essential for activities that people already know how to do well. But warning system personnel retire, and unfamiliar hazards can occur.

Second, some warning events are protracted enough that protective public action—for example, evacuation—can be elicited without plans. However, the nation cannot count on having enough lead time to accomplish effective warning in the absence of planning.

In fact, poor warnings are almost always a result of poor planning. Thus, while planning is not always necessary, it can help facilitate effective warnings. Planning for warning probably increases in importance as the frequency of experience with a particular hazard decreases. This suggests that planning for warning of events not yet experienced—for example, nuclear attack or a great urban earthquake—may be more fruitful than planning for events often experienced. Most of the hazards addressed in this work occur infrequently enough in a particular locale to make planning essential for them all.

7.5.2 Knowing the Public

The American public is diverse, and the relevance of that diversity for warning preparedness has already been reviewed (Sect.5). It is inappropriate to cast the public in the role of potential evacuees waiting for a short warning message from the county executive before beginning to engage in protective actions that must take place within a few minutes. This assumption of instant public response appears often enough to suggest that many warning systems are based on an inaccurate model of public behavior. Public warnings must speak to a diverse and heterogeneous public. The presumption of a simple stimulus-response model of public warning response is invalid and must be laid to rest.

7.5.3 Warning System Failures

There is no foolproof warning system. Every warning system has the potential for failure, or at least for functioning less effectively than originally intended. Consequently, disaster losses in terms of lives lost and injuries can never be reduced to zero. Warning systems are the final line of defense against disaster. When other strategies (control works, structural resistance,

land use, safety systems, diplomacy, and so on) fail and disaster is imminent, warning systems can serve to minimize the number of people in harm's way.

APPENDIX A

ORGANIZATIONAL EFFECTIVENESS

A.1 ORGANIZATIONAL EFFECTIVENESS

FACTORS

Specification of jobs/tasks (+)

Specification of authority (+)

Task boundaries (+)

Specification of priorities (+)

Normativeness of emergency tasks (+)

Legitimacy (+)

Threat perception (+)

REFERENCES

(see Sect. A.3 for complete bibliographic data.)

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Dynes et al. 1972
Adams 1970
Kennedy 1970
Dynes 1969, pp. 176, 203
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Barton 1962, p. 225
Form and Nosow 1958
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Form and Nosow 1958
Haas and Drabek 1973
Kennedy 1970
Dynes 1969, pp. 176, 203
Thompson 1967
Dynes et al. 1972, pp. 37, 54
Drabek and Haas 1969b, p. 37
Dynes 1969, p. 179
Drabek 1965
Adams 1970
Anderson 1969a, p. 254
Quarantelli and Dynes 1977
Thompson and Hawkes 1962
Mileti et al. 1975
Barton 1970
Dynes 1970b
McLuckie 1970
Anderson 1969b
Moore 1956
Eliot 1932
Dynes 1970b
Quarantelli and Dynes 1977
Dynes 1969
Thompson and Hawkes 1962
Form and Nosow 1958, p. 176
Anderson 1969b
Fritz 1961
Fritz and Williams 1957
Spiegel 1957
Instituut voor Sociaal Orderzoek von het
Nederlandse Volk Amsterdam 1955

Knowledge of task (+)	Stallings 1978 Haas and Drabek 1973 Dynes et al. 1972
Communication effectiveness (+)	Leik et al. 1981 Mileti et al. 1975 Kennedy 1970
Decision clarity (+)	Drabek et al. 1981 Quarantelli 1970, p. 389 Drabek and Haas 1969a Drabek and Haas 1969b, p. 37 Drabek 1965
Resource adequacy (+)	Kreps 1978 Dynes et al. 1972
Flexibility (+)	Drabek et al. 1981 Kreps 1978 Stallings 1978 Weller 1972, p. 151 Brouillette and Quarantelli 1971 Haas and Drabek 1970 Drabek and Haas 1969a Drabek and Haas 1969b Dynes and Warheit 1969 Warheit 1968 Dynes 1966 Moore 1956, p. 736 Barton 1962, p. 225 Form and Nosow 1958

A.2 ORGANIZATIONAL COORDINATION

Knowledge of task (+)	Dynes 1978, p. 61 Kreps 1978 Stallings 1978 Dynes et al. 1972 Kennedy 1970 Thompson and Hawkes 1962 Rosow 1955
Specification of authority (+)	Drabek et al. 1981 Thompson and Hawkes 1962, p. 279 Rosow 1955, p. 6
Legitimacy (+)	Dynes 1978, p. 51 Stallings 1978 Warheit 1970, p. 6
Specification of priorities (+)	Drabek et al. 1981 Kreps 1978 Stallings 1978
Size of network ()	Drabek et al. 1981

	Dynes 1978
	Dynes 1970b
	Kreps 1978
	Stallings 1978
	Quarantelli and Dynes 1977
	Warheit 1968
	Demerath and Wallace 1957
Routine interaction (+)	Dynes 1969
	Warheit 1968, p. 129
	Drabek et al. 1981
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	Brouillette 1971, p. 180
	Form and Nosow 1958, p. 112
	Clifford 1956
Prior disputes (⊖)	Drabek et al. 1981
	Dynes et al. 1972
	Dynes 1970b
	Warheit 1970
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System oversight (+)	Drabek et al. 1981
	Dynes 1978
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Communications (+)	Drabek et al. 1981
	Dynes 1978, p. 60
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	Drabek 1968
Ability to give up autonomy (+)	Quarantelli and Dynes 1977
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	Dynes 1970b, p. 170
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	Thompson and Hawkes 1962

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APPENDIX B

**FACTORS CORRELATED WITH HEARING, UNDERSTANDING, BELIEVING,
PERSONALIZING, RESPONDING TO, AND CONFIRMING WARNINGS**

B.1 FACTORS CORRELATED WITH HEARING WARNINGS

SENDER FACTORS

REFERENCES

(See Sect. B.7 for complete bibliographic data.)

Mass media (+)

Perry, Lindell, and Green 1982b, 201

Carter 1980, p. 5

Quarantelli 1980, p. 79

Broadcast media (+)

Hiroi, Mikami, and Miyata 1985, p. 23

Turner 1983, p. 316

Television (+)

Nelson et al. 1988, p. 22

Turner et al. 1981, p. 23

Turner et al. 1979, p. 116

Baker 1979, p. 12

Radio (+)

Dillman, Schwalbe, and Short 1981, p. 178

Dynes et al. 1979, p. 151

Drabek and Stephenson 1971

Turner 1983, p. 316

Newspapers in long-term (+)

Personal contact (+)

Perry and Lindell 1986, p. 65

Multiple channels (+)

Lindell and Perry 1987, p. 150

Turner et al. 1981, p. 26

RECEIVER FACTORS

REFERENCES

Observing cues (+)

Bellamy 1987, p. 3

Tierney 1987

Proximity to impact (+)

Lardry and Rogers 1982, p. 3

Rogers and Nehnevajsa 1984, p. 99

Lardry and Rogers 1982, pp. 3, 6

Frazier 1979, p. 343

Mileti et al. 1975, p. 45

Diggory 1956

Membership in voluntary
associations (+)

Perry, Lindell, and Greene 1981, p. 156

Perry and Lindell 1986, p. 68

Community involvement (+)

Perry and Greene 1982b, p. 327

Turner et al. 1981, p. 26

Sorensen and Gersmehl 1980, pp. 130, 133

Turner et al. 1979, p. 20

Scanlon and Frizzell 1979, p. 316

Frequent kinship interaction (+)

Lardry and Rogers 1982, p. 3

Perry and Greene 1982b, p. 3

Perry, Lindell, and Greene 1981, p. 155

Perry 1979, p. 35

Old age ()	Rogers 1985, p. 7 Gruntfest, n.d., p. 194 Perry, Lindell, and Greene 1981, pp. 156-7 Turner et al. 1979, p. 15 Perry 1979, p. 35 Turner 1976 Mileti 1975b, p. 22 Friedsam 1962, 1961 Mack and Baker 1961
Speaking the language (+)	Perry 1987, p. 144
Ethnicity ()	Nigg 1982
Network membership (+)	Rogers and Nehnevajsa 1987
Sleeping with windows open (+)	Nehnevajsa 1985, pp. 4, 9-12
Membership in social network (+)	Nehnevajsa 1985, pp. 13-14
High socioeconomic status (+)	Perry and Greene 1982b, p. 327 Turner et al. 1981, p. 25 Turner et al. 1979, p. 17
Having children (+)	Turner et al. 1981, p. 24 Turner et al. 1979, p. 19
Being a woman (+)	Turner et al. 1981, p. 25 Turner et al. 1979, p. 17
Membership in a subculture (+)	Perry, Lindell, and Greene 1981, pp. 102,157-158
Being at home (+)	Sorensen 1985, p. 13
Knowledge of disaster agent (+)	Turner et al. 1984, p. 24
Some of personal efficacy ()	Lardry and Rogers 1982, p. 3 Turner et al. 1981, p. 33
Prior disaster experience (+)	Perry and Lindell 1986, p. 27 Lardry and Rogers 1982, p. 3 Turner et al. 1981, pp. 25, 27 Anderson 1969

B.2 FACTORS CORRELATED WITH UNDERSTANDING WARNINGS

SENDER FACTORS

Specificity (+)

REFERENCES

Quarantelli 1984, p. 512
Greene, Perry, and Lindell 1981, p. 60
Perry et al. 1981
Warrick et al. 1981, p. 103
Perry and Greene 1980, p. 61
Drabek 1968
Rogers 1985, p. 5
Sorensen 1985, p. 13
Warrick et al. 1981, p. 103

Consistency (+)

Certainty (+)

Use of sirens only ()
Media with adequate information (+)
Multiple channels (+)
Frequency (+)

Official source (+)
Clarity (+)

Tierney 1987
Lachman, Tatsuoka, and Bonk 1961, p. 1406
Turner et al. 1981, p. 70
Carter 1980, p. 228
Rogers 1985, p. 5
Turner et al. 1981, p. 25
Mikami and Ikeda 1985, pp. 109-110
Rogers 1985, p. 5
Turner 1983, p. 323
Turner et al. 1979, p. 17
Quarantelli 1980, p. 120
Lehto and Miller 1986, p. 74

RECEIVER FACTORS

Geographical proximity (+)

Hazard-related employment (+)
Household size (+)
Discussion with others (+)
Length of community residence (+)
Community attachment (+)
Rural residence (+)
School-aged children (+)
Education (+)

Age (+)

Hazard knowledge (+)

Perceived personal risk (+)
Perceived risk for property (+)
Belief in science to predict (+)
Thought about hazard (+)
Hazard experience (+)

Majority group membership ()

Hazard experience ()

REFERENCES

Hodge, Sharp, and Marts 1979, p. 232
Diggory 1956
Perry and Lindell 1986, p. 55
Nehnevajsa 1985, p. 5
Turner et al. 1981, pp. 25, 70
Hodge, Sharp, and Marts 1979, p. 214
Turner et al. 1979, p. 20
Oliver and Reardon 1982, p. 53
Perry and Lindell 1986, p. 56
Turner et al. 1981, p. 25
Turner et al. 1979, p. 17
Turner et al. 1981, p. 25
Turner et al. 1979, p. 15
Lehto and Miller 1986, p. 81
Perry and Lindell 1986, p. 52
Foster 1980, pp. 76-77
Haas, Cochrane, and Eddy 1977
Perry and Lindell 1986, p. 48
Perry and Lindell 1986, p. 50
Turner et al. 1981, p. 25
Perry and Lindell 1986, p. 46
Perry and Greene 1983, p. 64
Perry, Lindell, and Greene 1981, p. 125
Quarantelli 1980, p. 40
Smith and Tobin 1979, p. 108
Drabek and Boggs 1968
Perry 1987, p. 145
Demerath 1957
Quarantelli 1980, p. 40
Hultaker 1976, pp. 19-21

PROCESS FACTORS

Confirmation (+)

REFERENCES

Perry 1982, p. 62
Hammarstrom-Tornstam 1977, pp. 16-17

B.3 FACTORS CORRELATED WITH BELIEVING WARNINGS

SENDER FACTORS

Specificity (+)

REFERENCES

Quarantelli 1984, p. 512
Perry and Greene 1982, pp. 326-327
Perry, Lindell, and Greene 1982a, pp. 100, 103
Sorensen 1982, p. 20
Greene, Perry, and Lindell 1981, p. 60
Perry, Lindell, and Greene 1981, p. 153
Lindell, Perry, and Greene 1980, p. 13
Perry and Greene 1980, p. 61

Consistency (+)

Perry 1979, p. 34
Drabek 1969, 1968
Fritz 1957
Sorensen 1982, p. 20
Turner et al. 1981, p. 64
Foster 1980, p. 1920
Mileti 1975b, p. 21
Withey 1962
Mack and Baker 1961
Goldstein 1960
Schatzman 1960
Demerath 1957
Fritz 1957
Clifford 1956

Certainty (+)

University of Oklahoma Research Institute 1953
Nigg 1987, p. 109
Mileti, Hutton, and Sorensen 1981, p. 79
Perry, Lindell, and Greene 1981
Turner et al. 1979, p. 61

Personal channel (+)

Mileti and Beck 1975, pp. 43-44
Nigg 1987, p. 111
Perry and Greene 1983, pp. 55-57
Perry, Greene, and Mushkatel 1983, p. 69
Sorensen 1982, p. 20
Perry, Lindell, and Greene 1981, p. 53
Moore et al. 1963
Clifford 1956

Electronic media (+)	Nigg 1987, p. 111 Perry and Greene 1983, p. 52 Perry, Greene, and Mushkatel 1983, p. 68 Perry and Greene 1980, p. 52 Flynn 1979, p. 24
Printed media (+)	Turner et al. 1979, p. 120
Multiple channels (+)	Turner et al. 1981, p. 29
Frequency (+)	Perry and Greene 1983, p. 66 Turner 1983, p. 312 Perry and Greene 1982b, pp. 326-327 Sorensen 1982, p. 20 Perry, Lindell, and Greene 1981, p. 156 Turner et al. 1981, pp. 69-70 Baker 1979, p. 13 Perry 1979, p. 34 Mileti 1975, p. 21 Mileti and Beck 1975, p. 41 Drabek 1969 Drabek and Boggs 1968 Fritz 1961
Official source (+)	Nigg 1987, p. 110 Rogers 1985, p. 6 Rogers and Nehevajsa 1984, p. 113 Perry and Greene 1983, p. 50 Perry, Greene, and Mushkatel 1983, p. 66 Sorensen 1982, p. 20 Leik et al. 1981 Perry 1981 Perry and Greene 1980, p. 50 Quarantelli 1980, p. 120 Flynn 1979, p. 23 Mileti 1975b, p. 21 Wenger 1972, pp. 52-53 Drabek 1969 Drabek and Boggs 1968 Lachman, Tatsuoka, and Bonk 1961, p. 1407 Lehto and Miller 1986, p. 95 Perry 1982, pp. 62-63 Perry and Greene 1982b, pp. 326-327 Mileti, Hutton, and Sorensen 1981, p. 79 Turner et al. 1981, pp. 10, 22, 28 Perry 1979, p. 34 Turner et al. 1979, p. 37 Committee on the Socioeconomic Effects of Earthquake Prediction 1978, p. 18 Simpson and Riehl 1981, p. 290
Credibility (+)	
Source familiarity (+)	

RECEIVER FACTORS

Cues (+)

Geographical proximity (+)

United family (+)

With peers ()

In large organization ()

Being a woman (+)

Age ()

High socioeconomic status (+)

Minority group membership ()

Hazard knowledge (+)

Perceived personal risk (+)

Belief in science to predict (+)

Some personal efficacy (+)

Time to impact ()

Stress ()

REFERENCES

- Tierney 1987
Saarinen and Sell 1985, p. 156
Perry and Greene 1982b, pp. 326-327
Sorensen 1982, p. 20
Quarantelli 1980, p. 107
Mileti 1975b, p. 21
Drabek 1969, pp. 343-344
Mack and Baker 1961, p. 46
Sorensen 1982, p. 20
Turner et al. 1981, p. 14
Flynn and Chalmers 1980, p. 51
Diggory 1956
Drabek and Stephenson 1971
Mack and Baker 1961
Mack and Baker 1961
Clifford 1956
Moore et al. 1963
Mack and Baker 1961
Turner et al. 1981, p. 27
Yamamoto and Quarantelli 1982, p. 44
Drabek 1969
Mack and Baker 1961
Turner et al. 1981, p. 27
Hodge, Sharp, and Marts 1979, p. 229
Friedsam 1962, 1961
Mack and Baker 1961
Perry 1987, p. 148
Sorensen 1982, p. 20
Turner et al 1981, p. 27
Mileti et al. 1975, p. 47
Nigg 1987, p. 111
Perry, Lindell, and Greene 1982a, p. 103
Turner 1976, p. 1983
Moore et al. 1963, p. 125
Leik et al. 1981, pp. 433-434
Rogers 1985, p. 12
Perry and Greene 1983, p. 101
Perry, Greene, and Mushkatel 1983, p. 280
Yamamoto and Quarantelli 1982, p. 44
Turner et al. 1981, pp. 27, 29
Turner et al. 1979, p. 29
Turner et al. 1981, p. 27
Sorensen 1982, p. 20
Quarantelli 1980, p. 107

Hazard experience (+)

Hodler 1982, p. 46
Perry and Greene 1982b, pp. 326-327
Sorensen 1982, p. 20
Turner et al. 1981, pp. 27, 29, 51
Foster 1980, pp. 76-77
Perry and Greene 1980, p. 64
Quarantelli 1980, p. 40
Perry 1979, p. 34
Haas, Cochrane, and Eddy 1977
Hultaker 1976, p. 19
Turner 1976, p. 182
Ponting 1974, p. 11
Drabek and Boggs 1968
Fritz 1961
Mack and Baker 1961
Demerath 1957
Williams 1957
Wallace 1956
Instituut voor Sociaal Onderzoek van het
Nederlandse volk Amsterdam 1955
University of Oklahoma Research Institute 1953
Nigg 1987, p. 111
Breznitz 1984, p. 123
Hodge, Sharp, and Marts 1979, p. 229

Hazard experience ()

PROCESS FACTORS

Confirmation (+)

REFERENCES

Quarantelli 1984, p. 512
Perry, Greene, and Mushkatel 1983, p. 287
Hodler 1982, p. 46
Nigg 1982
Perry and Greene 1982b, pp. 326-327
Perry, Lindell, and Greene 1981, p. 31
Perry and Greene 1980, p. 75
Irish and Falconer 1979, p. 323
Mileti and Beck 1975, p. 41
Drabek and Stephenson 1971
Drabek 1969
Drabek and Boggs 1968
Withey 1962
Danzig et al. 1958

B.4 FACTORS CORRELATED WITH PERSONALIZING WARNINGS

SENDER FACTORS

Specificity (+)

Nigg 1987, p. 111
Perry and Greene 1983, pp. 60-61
Perry, Greene, and Mushkatel 1983, pp. 62, 282
Perry and Greene 1982b, p. 327
Perry, Lindell, and Greene 1982a, pp. 101-103
Perry, Lindell, and Greene 1981, p. 153
Perry, Lindell, and Greene 1980, p. 13
Perry 1979, p. 34

Consistency (+)

Nigg 1987, p. 111
Lindell and Perry 1983, p. 52
Foster 1980, p. 192

Source familiarity (+)

McDavid and Harai 1968

Frequency (+)

Perry, Lindell, and Greene 1981, p. 154
Perry, Lindell, and Greene 1982b, p. 201
Turner et al. 1981, p. 31
Perry 1979, p. 34

Official source (+)

Mileti and Beck 1975, p. 39

Credible source (+)

Perry, Lindell, and Greene 1981, p. 52
Rogers and Nehnevajsa 1987
Perry, Greene, and Mushkatel 1983, p. 66
Perry and Greene 1982b, p. 327

Clarity (+)

Perry 1979, p. 34
Nigg 1987, p. 111

RECEIVER FACTORS

Cues (+)

Geographical proximity (+)

REFERENCES

Perry and Greene 1982b, p. 327

Rogers and Nehnevajsa 1987

Perry and Lindell 1986, p. 85

Flynn 1979, p. 32

Low socioeconomic status (⊖)

Perry and Greene 1982, p. 327

Yamamoto and Quarantelli 1982, p. 44

Mileti, Hutton, and Sorensen 1981

High socioeconomic status (+)

Flynn 1979, p. 29

Age (⊖)

Flynn 1979, p. 29

Being a woman (+)

Yamamoto and Quarantelli 1982, p. 44

Flynn 1979, p. 29

Hodge, Sharp, and Marts 1979, p. 239

Membership in disenfranchised ethnic group (-)

Perry, Lindell, and Greene 1982a, p. 101

Perry and Greene 1982b, p. 327

Hazard knowledge (+)	Perry and Lindell 1986, p. 95 Turner et al. 1981, p. 31
Some of personal efficacy (+)	Turner et al. 1979, p. 51 Turner et al. 1981, p. 33
Perceived personal risk (+)	Perry and Lindell 1986, p. 37 Turner et al. 1981, p. 52
Hazard experience (+)	Nigg 1987, p. 112 Rogers and Nehnevajsa 1987 Saarinen et al. 1984, p. 66 Hannson, Nowlles, and Bellovich 1982, p. 184 Perry and Greene 1982b, p. 327 Perry, Lindell, and Greene 1981, p. 70 Turner et al. 1981, p. 31 Perry 1979, p. 34

PROCESS FACTORS

Understanding (+)
Belief (+)
Confirmation (+)

REFERENCES

Hodler 1982, p. 46
Perry and Greene 1983, p. 101
Nigg 1987, p. 113
Perry and Greene 1982b, p. 327
Perry, Lindell, and Greene 1981, p. 152

B.5 FACTORS CORRELATED WITH WARNING RESPONSE

SENDER FACTORS

Specificity (+)

REFERENCES

Bellamy and Harrison 1988, p. 5
Nelson et al. 1988, p. 14
Lindell and Perry 1987, pp. 139-140
Nylen and Hultaker 1987, p. 34
Rogers 1985, pp. 11, 16
Gruntfest, n.d., p. 195
Houts et al. 1984, p. 36
Perry 1983, p. 43
Perry and Greene 1983, pp. 60-61
Ikeda 1982, p. 55
Moore et al. 1982, p. 26
Perry and Greene 1982b, p. 326
Paulsen 1981, pp. 12-13
Perry 1981, p. 60
Perry, Lindell, and Greene 1981, p. 152
Simpson and Riehl 1981, p. 290

	Carter 1980, p. 228
	Flynn and Chalmers 1980, p. 21
	Perry and Greene 1980, p. 60
	Quarantelli 1980, p. 104
	Dynes et al. 1979, p. 152
	Flynn 1979, p. 19
	Perry 1979, p. 34
	Sime 1979, pp. 211-214
	Mileti and Beck 1975, p. 45
Consistency (+)	Nigg 1987, p. 111
	Chiu et al. 1983, p. 115
	Perry 1983, p. 43
	Turner et al. 1981, p. 40
	Perry 1981, p. 53
	Quarantelli 1980, p. 104
	Flynn 1979, p. 18
Clarity (+)	Mileti et al. 1975, p. 48
	Bellamy and Harrison 1988, p. 7
	Nigg 1987, p. 111
	Gruntfest, n.d., p. 195
	Quarantelli 1980, p. 104
	Mileti et al. 1975, p. 48
Channel (o)	McLuckie 1975, p. 48
Face-to-face channel (+)	Baker 1979, p. 12
	Cutter 1987, p. 29
	Gray 1981, p. 363
Mass media (+)	Perry, Lindell, and Greene 1981, p. 133
	Flynn 1979, p. 21
	Windham et al. 1977, p. 33
Frequency (+)	Mileti and Beck 1975, p. 39
	Perry, Lindell, and Greene 1981, p. 156
	Quarantelli 1980, p. 104
	Turner et al. 1979, p. 108
	Gruntfest 1977, p. 19
	Mileti and Beck 1975
	Drabek 1969
	Lachman et al. 1961
	Fritz and Mathewson 1957
	Fritz and Marks 1954
Time to impact ()	Cutter 1987, p. 15
	Gruntfest, n.d., p. 195
	Chiu et al. 1983, p. 115
	Perry, Greene, and Lindell 1980, p. 440
	Quarantelli 1980, p. 104
	Hultaker 1976, p. 9

Official source (+)

Baker 1987, p. 17
Bellamy 1987, p. 5
Baker 1986, p. 20
Rogers 1985, p. 15
Saarinen and Sell 1985, p. 161
Baker 1984, p. 66
Perry 1983, p. 40
Goldstein and Schorr 1982, p. 51
Perry and Greene 1982, p. 89
Perry 1981, p. 57
Perry, Lindell, and Greene 1981, p. 53
Perry and Greene 1980, p. 55
Quarantelli 1980, p. 73
Windham et al. 1977, p. 33
Treadwell 1962, p. 24

Scientific source (+)

Sorensen 1984

Source credibility (+)

Flynn 1979
Perry 1987, p. 149
Cutter 1987, p. 15
Gruntfest, n.d., p. 195
Stallings 1984, p. 13
Lindell and Perry 1983, p. 52
Perry, Lindell, and Greene 1981, p. 152
Simpson and Riehl 1981, p. 290
Quarantelli 1980, p. 104
Turner 1976, p. 183
McLuckie 1970

Source familiarity (+)

Lindell and Perry 1987,
pp. 145-146
Perry and Lindell 1986, p. 122
Perry 1983, p. 41
Perry and Greene 1982, p. 89
Perry 1981, p. 57
Perry, Lindell, and Greene 1981, p. 53
Perry and Greene 1980, p. 55

RECEIVER FACTORS

Social cues (+)

REFERENCES

Cutter 1987, p. 17
Rogers and Nehnevajsa 1987
Perry 1983, p. 41
Cutter and Barnes 1982
Perry and Greene 1982, p. 89
Perry 1981, p. 57
Christensen and Ruch 1980, pp. 207, 209

	Baker 1979, p. 21
	Frazier 1979, p. 344
	Dynes and Quarantelli 1976, p. 3
	Treadwell 1962, p. 24
Environmental cues (+)	Cutter 1987, pp. 16, 30
	Rogers and Nehnevajsa 1987
	Perry 1983, p. 40
	Perry and Greene 1982, p. 89
	Liverman and Wilson 1981
	Perry 1981, p. 51
	Perry, Lindell, and Greene 1981; p. 133
	Flynn 1979, p. 19
Geographical proximity (+)	Houts et al. 1984, p. 33
	Yamamoto and Quarantelli 1982, pp. 96-97
	Liverman and Wilson 1981
	Perry 1981, p. 60
	Baker 1979, pp. 18, 19
	Dynes et al. 1979, pp. 70, 151
	Flynn 1979, pp. 14, 17, 31
Membership in social networks (+)	Bellamy 1987, p. 5
	Rogers 1985, p. 15
	Anderson et al. 1984, p. 75
	Perry 1983, pp. 36, 41
	Mileti, Hutton, and Sorensen 1981, pp. 112-
114	
87, 155-156	Perry, Lindell, and Greene 1981, pp. 79,
	Turner et al. 1981, p. 39
	Perry, Lindell, and Greene 1980, p. 40
	Baker 1979, pp. 17-21
	Dynes et al. 1979, p. 152
	Perry 1979, p. 35
	Turner et al. 1979, p. 109
	Windham et al. 1977,
	pp. 27, 33
	Worth and McLuckie 1977, p. 72
	Gruntfest 1977
	Clifford 1956
Freedom to leave work (+)	Houts et al. 1984, p. 33
	Stallings 1984, p. 14
	Perry 1981, p. 60
	Baker 1979, p. 19
	Dynes et al. 1979, p. 152
	Flynn 1979, p. 19
United family (+)	Perry 1987, p. 147
	Cutter 1987, p. 29

	Perry and Greene 1983, p. 66
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	Perry, Lindell, and Greene 1981, p. 45
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	Perry, Lindell, and Greene 1980, p. 40
	Flynn 1979, p. 32
	Frazier 1979, p. 343
	Dynes and Quarantelli 1976, p. 4
	Quarantelli 1960
United family (o)	Mileti 1974
Resources (+)	Bellamy 1987, p. 5
	Houts et al. 1984, p. 33
	Mileti, Hutton, and Sorensen 1981
Being a parent (+)	Baker 1979, p. 21
	Houts et al. 1984, p. 33
	Carter, Kendall, and Clark 1983, pp. 102-103
	Perry 1981, p. 53
	Turner et al. 1981, p. 39
	Quarantelli 1980, p. 42-43
	Flynn 1979, p. 21
	Wilkinson and Ross 1970, p. 16
Socioeconomic status (+)	Stallings 1984, p. 14
	Mileti, Hutton, Sorensen 1981
	Turner et al. 1981, p. 39
	Baker 1979, p. 19
	Dynes et al. 1979, p. 152
	Flynn 1979, p. 32
	Windham et al. 1977, p. 24
	Wilkinson and Ross 1970, p. 16
	Lackman et al. 1961
Being a woman (+)	Yamamoto and Quarantelli 1982, p. 126
	Flynn and Chalmers 1980, p. 24
	Flynn 1979, p. 21
	Wilkinson and Ross 1970, p. 16
Age ()	Nelson et al. 1988, p. 20
	Baker 1987, p. 20
	Gruntfest, n.d., p. 194
	Bellamy 1987, p. 5
	Perry, Lindell, and Greene 1981, pp. 156-157
	Dynes 1979, p. 152
	Flynn 1979, p. 32
	Perry 1979, p. 35
	Gruntfest 1977, p. 23
	Mileti 1975b, p. 22
	Wilkinson and Ross 1979, p. 16

Age (+)	Moore et al. 1963 Cutter and Barnes 1982 Yamamoto and Quarantelli 1982, pp. 86, 174 Perry, Lindell, and Greene 1981, p. 93
Age (o)	Baker 1979, p. 21
Minority group membership (□)	Perry 1987, p. 145 Perry, Greene, and Mushkatel 1983, p. 45 Perry, Lindell, and Greene 1982a, pp.103-104; 1982b, p. 157-158 Perry, Lindell, and Greene 1981, p. 101 Turner et al. 1981, p. 40 Wilkinson and Ross 1970, p. 14 Drabek and Boggs 1968, p. 447
Being black (+)	Perry, Greene, and Mushkatel 1983, p. 43
Knowledge about protective response (+)	Lindell and Perry 1987, p. 139 Cutter 1987, p. 29 Rogers 1985, p. 15 Perry, Greene, and Mushkatel 1983, p. 281 Perry and Greene 1982, p. 326 Leik et al. 1981, pp. 433-434 Liverman and Wilson 1981 Perry, Lindell, and Greene 1981, p. 153 Warrick et al. 1981, p. 13 Perry, Lindell, and Greene 1980, p. 40 Perry 1979, p. 34 Windham et al. 1977, p. 54 Withey 1976, p. 129
Hazard knowledge (+)	Cutter 1987, p. 15 Sorensen 1986, pp. 438-457 Perry and Lindell 1986, p. 117 Dynes et al. 1979, p. 52
Some of personal efficacy (+)	Perry 1987, p. 151 Perry and Greene 1982b, p. 326 Turner et al. 1981, p. 40 Flynn 1979, p. 19
Fear of looting (□)	Sims and Bauman 1972, p. 1391 Quarantelli 1984, p. 513 Perry 1983, p. 43 Perry 1981, p. 60 Flynn 1979, p. 19
Habituation (□)	Pauls and Jones 1980 Glass 1970 Anderson 1968 Demerath 1957 Kilpatrick 1957

Perceived risk/loss (+)	Nelson et al. 1988, p. 19 Houts et al. 1984, p. 33 Mileti, Hutton, and Sorensen 1981 Baker 1979, pp. 18-19 Flynn 1979, pp. 17-21 Windham et al. 1977, p. 24
Fear over forced evacuation (+)	Perry 1981, p. 53 Flynn 1979, p. 18
Perceived time away from home (+)	Liverman and Wilson 1981 Perry, Greene, and Lindell 1980, pp. 440-441
Hazard experience (□)	Breznitz 1984, p. 78
Hazard experience (+)	Nylen and Hultaker 1987, p. 34 Rogers and Nehnevajsa 1987 Breznitz 1984, p. 81 Perry and Lindell 1986, pp. 119-120 Gruntfest, n.d., p. 194 Perry and Greene 1982, p. 326 Perry, Lindell, and Greene, 1981, pp. 70, 152-153 Turner et al. 1981, p. 39 Perry and Greene 1980, p. 66 Baker 1979, p. 17 Frazier 1979, p. 343 Irish and Falconer 1979, p. 323 Perry 1979, p. 34 Smith and Tobin 1979, p. 108 Westgate 1978, p. 25 Regan and Fazio 1977, p. 41 Hutton 1976, p. 265 Gruntfest 1976, 1977, p. 19 Turner 1976, p. 182 Lachman, Tatsuoka, and Bonk 1961, p. 1409 Treadwell 1962, p. 24
Recency of experience (+)	Perry, Lindell, and Greene 1981, p. 153 Perry, Greene, and Lindell 1980, p. 441 Hutton 1976, p. 265 Anderson 1969 Moore et al. 1963 Fogleman 1958
Amount of experience (+)	Perry, Greene, and Lindell 1980, p. 441
Amount of experience (□)	Windham et al. 1977 Baker 1979, pp. 16-17 Wilkenson and Ross 1970, p. 20

PROCESS FACTORS

Hearing (+)

Understanding (+)

Believing (+)

Personalization (+)

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Turner 1983, p. 328
Turner et al. 1981, p. 39
Baker 1979, p. 13
Turner et al. 1979, pp. 58-104
Gruntfest 1977
Turner 1983, p. 326
Baker 1979, p. 15
Turner et al. 1979, p. 108
Windham et al. 1977, p. 56
Wilkinson and Ross 1970, p. 31
Perry 1987, pp. 148-149
Perry 1983, p. 42
Perry and Greene 1983, p. 101
Perry, Greene, and Mushkatel 1983, p. 280
Perry and Greene 1981a, p. 343
Perry and Greene 1982b, pp. 326-327
Perry, Lindell, and Greene 1982a, pp. 99, 102
Perry, Lindell, and Greene 1981, pp. 154-155
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Perry and Greene 1980, pp. 78-80
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Baker 1979, pp. 13-16
Perry 1979, p. 34
Hultaker 1976, p. 8
Mileti and Beck 1975, p. 45
Baker 1987, pp. 16, 19, 33-34
Perry 1987, p. 149
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Gruntfest, n.d., p. 195
Quarantelli 1984, p. 512
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Perry 1983, pp. 36-40
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Ikeda 1982, p. 55
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Perry and Greene 1982a, p. 343
Perry and Greene 1982b, p. 327
Perry, Lindell, and Greene 1982, pp. 99, 102
Yamamoto and Quarantelli 1982, pp. 96-97
Mileti, Hutton, and Sorensen 1981, pp. 79, 100, 107

	Perry 1981, pp. 53-60
	Perry, Lindell, and Greene 1981, pp. 39-40, 72, 78, 151, 158
	Baker 1979, pp. 14-19
	Dynes et al. 1979, p. 152
	Turner et al. 1979, p. 106
	Flynn 1979, p. 29
	Perry 1979, p. 34
	Windham et al. 1977, pp. 51-59
	Hultaker 1976, p. 8
	Withey 1976, p. 128
	Mileti and Beck 1975, p. 39
	Glass 1970, pp. 64-67
	Bates et al. 1963
	Demerath 1957
	Fritz 1957
Confirmation (+)	Bellamy and Harrison 1988, p. 5
	Rogers 1985, p. 16
	Perry, Greene, and Mushkatel 1983, p. 286
	Leik et al. 1981, p. 36-39
	Paulsen 1981, p. 14
	Irish and Falconer 1979, p. 323
	Drabek 1969, p. 344

B.6 FACTORS CORRELATED WITH CONFIRMING WARNINGS

FACTORS

REFERENCES

Hearing (+)	Rogers 1985, p. 16
	Perry, Greene, and Mushkatel 1983, p. 286
	Leik et al. 1981, pp. 36-39
	Paulsen 1981, p. 14
	Irish and Falconer 1979, p. 323
	Drabek 1969, p. 344
Time to impact (+)	Perry, Lindell, and Greene 1981, pp. 31, 152
Perceived risk (+)	Nylen and Hultaker 1987, p. 31
	Leik et al. 1981, pp. 433-434
	Danzig et al. 1958
Media source (+)	Dillman, Schwalbe, and Short 1981, p. 176
	Frazier 1973, p. 343
	Drabek 1969, p. 343
Family unity (+)	Drabek and Stephenson 1971
Frequency ()	Mileti 1975b, p. 21
Hazard knowledge (+)	Rogers 1985, p. 14
Specificity (+)	Perry and Greene 1983, pp. 60-61

Certainty (□)
Frequency (+)

Cutter and Barnes 1982
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Nigg 1982

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APPENDIX C

TELEPHONE OVERLOAD DURING EMERGENCIES

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TELEPHONE OVERLOAD DURING EMERGENCIES

C.1 INTRODUCTION

The purpose of this appendix is to report on the findings of a survey designed to gather information about telephone system overload in emergencies. We have ignored the problems of physical destruction and busy numbers and have focused instead on system overload due to the increased use of telephones in communities experiencing an emergency. The use of telephones increases above normal use rates during emergencies. This phenomenon is well illustrated by anecdotal evidence in historical emergencies. Warning studies indicate that members of the public use telephones to receive and give informal warnings to others, and some studies indicate that respondents were unable to use the telephone for communication because the lines were disrupted or busy.

There are several reasons that could account for problems with the use of telephones in emergencies. First, it is possible that available equipment is simply overloaded because of increased use. Second, many emergencies result in destruction of phone lines. Exposed lines are most vulnerable in such emergencies tornadoes and hurricanes; earthquakes can disrupt buried lines as well. Third, certain telephones, such as those at city and county emergency offices, are used more in emergencies than others. Consequently, people have trouble getting through to such offices.

C.1.1 The Survey

Over a dozen telephone companies were included in this survey. These companies were purposefully selected. We sought to include companies that were local, regional, and national in terms of service delivery. We also included companies that had delivered service in an area that recently experienced a major emergency. Emergencies that had large physical impacts were included only if they had long pre-impact warning periods so that we could obtain information about increased telephone use before systems were damaged.

Interviews were conducted by telephone. The respondents selected were in jobs of operations management with emergency responsibilities. Interviewers used a questionnaire composed of semistructured open-ended questions. The focus of these questions was on several factors. We sought information on (1) whether or not overload has occurred or can occur, (2) the impact of new technology on handling overload, and (3) managing overload, for example, through rerouting calls or assigning priorities to lines.

C.1.2 Findings and Conclusions

No company reported that it was aware of any problems of telephone system overload during an emergency. However, all said that records specific to the overload issue during emergencies are not kept by their companies, and most company spokespersons agreed that the central switching office for an area experiencing an emergency could indeed become overloaded.

Most respondents reported that because of the sophistication of new technology, overload should rarely become a problem. Technological advances that help reduce the potential

for overload include the capability of rerouting calls through other switching stations almost anywhere in the nation. This service is most available for long distance calls, and the major national telephone companies have this rerouting capacity for both local and long distance calls. However, it was reported that there is little coordination between national and regional companies for using this capacity in local emergencies.

Technological advancements have also not been evenly adopted in all areas of the nation, nor by all telephone companies. The contribution of new technology to mitigating the possible problem of overload in emergencies is best viewed as a site-specific issue.

There are several ways to manage overload by implementing priorities. First, many local phone offices can restrict selected customers from using the telephone during emergencies by limiting dial tones. Second, line-load control programs are in place in many parts of the country. A control program could give priority to designated emergency lines. Some companies have designated priority circuits, for example, for use by the U.S. government. Third, some systems prioritize calls on a first come, first served basis. New technology takes calls in the order that they were made on public use lines.

On October 17, 1987, people calling for World Series tickets in Minneapolis created a telephone gridlock (Linec 1988). Delays in getting a dial tone ran from several seconds to about 15min. In one central office serving 42,000 numbers, 615,000 calls passed through the office while a normal load was 60,000 calls. That system allows 170 simultaneous dial tones, about 0.4% of all phones. It is unclear how many phones could be in service at once.

At present, it does seem that overload can be a problem in future emergencies. However, there are ways to design the problem out of the system as well as ways to manage the problem should it occur. The adoption of these solutions is varied, site-specific, and variable from company to company. For example, at present at least one national company is working with the Federal Emergency Management Agency to obtain telecommunications backup hardware.

C.3 REFERENCE

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