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Flash flood mitigation: recommendations for research and applications

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Abstract

New technologies promise reduced flash flood losses. However, real-time observations with vast multi-sensor networks, more precise mapping capabilities using remote sensing and GIS, quicker hydrological and meteorological models, and increasing forecast lead times have not reduced losses. In November, 1999, 35 researchers from nine countries met in Ravello, Italy at a NATO sponsored Advanced Study Institute, to discuss these issues and to develop a research agenda that incorporates the various components required to cope with flash floods. The key recommendations from the Institute were: (1) greater emphasis on increasing understanding of the social processes involved in flash flood warning, particularly in the response phases, and (2) the need to reduce vulnerability in sustainable ways compatible with long-term economic and social goals. The relationship between hydrometeorology and social science is seen as critical to advancing our abilities to cope with flash floods.

Keywords: Flash flood; Vulnerability; Warning; Social science

1. Introduction

In November, 1999, 27 people were killed in flash flooding in southwestern France. At the time of those floods, 35 scientists and practitioners, representing a range of specialties from meteorology to engineering to social science, were meeting at a NATO sponsored Advanced Study Institute, "Coping with Flash Floods". The flash floods in France and many other similar events elsewhere formed the basis of discussion, with an emphasis on how to reverse the trend toward increased losses. Hydrological and meteorological uncertainty with regard to flash flood conditions continues to present difficulties, yet progress is being made, as models are being enhanced by real-time observations that are part of vast multi-sensor networks. As a result, lead times for forecasting are increasing. Despite all of these promising advances, loss of life and damage to property continue without any indications of decreased vulnerability.

Institute participants urge that attempts to lessen the flash flood hazard must be comprehensive in nature, recognizing the relative importance of hydrometeorological information and socio-economic characteristics. Although significant progress has been made in both areas, there is much to be learned. Fig. 1 presents several possible combinations of knowledge and uncertainty with respect to the physical and human environments (represented by hydrometeorology and social science, respectively). The preferred position on the graph is C, where uncertainty on both axes is minimal. Unfortunately, the current situation is more like points A and B, where uncertainty is high in some cases and lower in others. Of course, the location of the points will be different for different places, but the general scheme shows the direction in which we want to move—to the upper right-hand corner of the graph.

These challenges were addressed at the Institute. While the group was unable to solve any of the difficult issues that are associated with coping with flash floods, a number of recommendations on both research and application resulted from the Institute. This paper focuses on four of them:

1. improvements in forecasting and warning are required to include changes in message dissemination and uses of forecasts and warnings;
2. existing knowledge and the results of research on flash floods must be applied to loss reduction directly;

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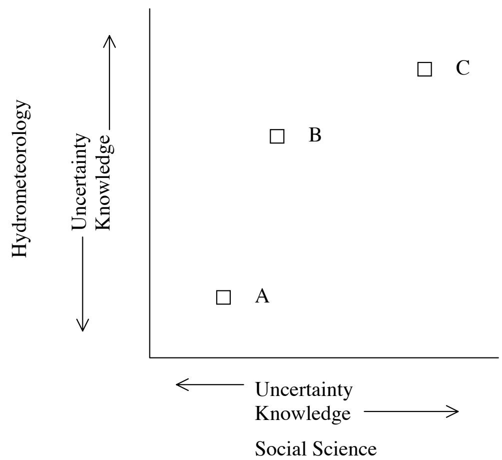

Fig. 1. Conceptual model.

3. social science components and links require the most attention; and
4. sustainable flash flood mitigation policies that take a long-term outlook must be developed.

Each is discussed in detail below, following background information on flash flooding and recent losses.

2. Flash flood conditions and losses

One of the greatest difficulties in addressing flash flood problems is defining them. It is generally agreed that flash floods have the following characteristics:

1. they occur suddenly, with little lead time for warning;
2. they are fast-moving and generally violent, resulting in a high threat to life and severe damage to property and infrastructure;
3. they are generally small in scale with regard to area of impact;
4. they are frequently associated with other events, such as riverine floods on larger streams and mudslides; and
5. they are rare (Gruntfest and Handmer, 2001).

Several important factors arise as a result of these characteristics. First, areas prone to flash flood need to be prepared. Because such events usually come as surprises, warning and preparation are essential; however, because they are rare, the motivation to invest time and resources into such activities is low. Because flash floods usually affect relatively small areas, losses resulting from them do not always generate much long-term response, unless there is high loss of life; however, losses per unit (acre, square mile, or kilometer) of area affected tend to be high compared to other events like riverine floods or hurricanes. Finally, it is sometimes very difficult to attribute specific losses to flash flood events, particularly when they occur in combination with other events. Thus, losses may be underestimated in many instances.

The information in Table 1 outlines losses to flash flood events in recent years, as compiled by the Flash Flood Laboratory at Colorado State University and recent news reports. It is apparent from this list that flash floods exact a high toll, but it is variable from place to place and from time to time. Some of the differences can be attributed to differences in warning and preparation, others result from different hydrometeorological situations, and still others can be attributed to large storms precipitating the flash flood events compared to isolated flash flood occurrences. For example, the death tolls resulting from Hurricane Mitch in October, 1998, and from the Venezuelan floods in December, 1999 stand out and seem to contradict one of the characteristics of flash floods mentioned earlier, that of them being of generally small scale. Clearly, there are some places in which large numbers of people are at risk.

The statistics in the table also suggest that losses are not diminishing. Indeed, many believe that losses to flash floods will rise in the future, in part because of climate change, but also because of increases in human activities in flash flood prone areas (Gruntfest and Handmer, 2001). Human activity is expanding into more hazardous areas, particularly in or next to mountainous regions. The Antelope Canyon event and the Swiss event, shown in Table 1, are good examples of increased use of extremely hazardous areas for recreation. In addition, urban and suburban development continues in high hazard areas, putting more people and property at risk and increasing the need for accurate and timely warnings. The 1999 events in France and Sudan are examples of this.

Clearly, then, flash floods continue to take large tolls, and, without intentionally addressing all parts of the hazard (physical, social, and economic), they can be expected to increase. Losses will increase in known high-risk areas unless forecasts, warnings, and preparedness are all addressed. Losses will also increase as a result of more areas becoming hazardous through unwise or unregulated urban development that affects stormwater flow, runoff relationships, and patterns of human occupancy. And, losses will increase everywhere because of changing hydrometeorological conditions. The recommendations from the Institute follow from these factors, and are discussed in detail below.

3. The recommendations

3.1. Improvements in forecasts and warnings

As research has progressed on the science and technology of forecasting and warning systems, so has the recognition that the elements of these systems are

Table 1
Recent losses to flash floods

Date	Location	Deaths	Other losses	Additional information
July, 1997	Fort Collins, CO, USA	5	\$200 M in damages (\$100 M to Colo. State Univ.)	
August, 1997	Antelope Canyon, AZ, USA	11 (13 missing)		Tourists and hikers killed
April, 1998	Mossel Bay, South Africa	0	200 evacuated or lost homes	
May, 1998	Moray Firth, Scotland	0	128 displaced	
August, 1998	Tibet and Midwest Nepal	156	800 displaced	
October, 1998	Wad-Sulayman Valley, Sudan	63	Most of livestock in area killed	Nomadic tribe affected
October, 1998	Central America—Hurricane Mitch	10,000	Billions of dollars in damage	Combination of flooding and flash flooding
January, 1999	Fiji	At least 1	Several missing; hundreds homeless	
February, 1999	Agusan River, Philippines	24	50,000 displaced; damage > \$3.2 M	
February, 1999	Mindanao Island, Philippines	39	2700 displaced	
July, 1999	Forest Falls, CA, USA	1	At least six houses destroyed	1.5″ rain in 30 min; 15′ wall of water down canyon
July, 1999	Switzerland	21	"Canyoning" group	
July/August, 1999	Vietnam	40	22,000 evacuated or lost homes; ~\$19.5 M in damages	
July/August, 1999	Thailand	6	30,000 evacuated or lost homes	
August, 1999	Khartoum, Sudan	0	Numerous homes and other property destroyed	
August, 1999	Chenzhou City, China	77	120,000 displaced; ~\$200 M in damages	30 cm rain in 24 h
August, 1999	Mekong River, Cambodia	> 8	8000 displaced; millions in damages	
August, 1999	SW of Tokyo, Japan	> 2	Several missing, presumed dead	Camping sites washed away; holiday time
August, 1999	Saxeten River, Switzerland	19	6 injured; 2 missing, presumed dead	
October, 1999	Gulf Coast of Mexico	600	Hundreds missing; > 200,000 evacuated	Floods, flash floods, and mudslides
November, 1999	SW France	27	Thousands displaced; major infrastructure destroyed	Flash floods and mudslides
December, 1999	Southern Thailand	5		
December, 1999	Caribbean coast, Venezuela	Up to 30,000	~400,000 homeless; 90,000 homes destroyed	Flash flooding and mudslides
May, 2000	Indonesian West Timor	81	100,000 people affected, 35,000 displaced	Flash floods
May, 2000	St. Louis, MO USA	2	Hundreds of people evacuated, flash floods also hit Tulsa other Oklahoma communities	14 inches of rain over night
July, 2000	Vietnam	24	Five homes, 250 m of canals, 20 irrigation systems and 7 power pylons	Flash floods and landslides
September, 2000	Italy	13	Campsite on Beltrame River—officials being sued	
November, 2000	West Sumatra	60	10 provinces hit, 584,000 affected	Flash floods and landslides
February, 2001	Malawi	7	100,000 displaced	
May, 2001	Northern Thailand	22	600 houses damaged, dozens destroyed	285 mm of rain plus 67 mm the following day
June, 2001	Ghana	6	Tens of thousands forced to flee their homes	5 h of heavy rain

Source: Flash Flood Lab, Colorado State University, 2000 and news reports.

intricately related and build on one another (Doswell et al., 1996). Real-time observations, combined with hydrometeorological models, allow for increasingly accurate and timely forecasts and warnings. Meteorological features, such as precipitation intensity, distribution, and amounts, as well as hydrologic responses to these variables, are being incorporated into models aimed at improving understanding of rainfall–runoff relationships, upon which forecasts and warnings are based (see Rochette and Moore, 1996; Schwein, 1996 for examples of each). The more we understand these factors, particularly the relationships between them in small watersheds, the greater the improvements in forecasts and warnings will be. However, this is complicated by characteristics of the meteorological and hydrological systems generating flash flood conditions. As Kelsch et al. (2001, p. 20) point out, "High intensity rainfall is more important than the total accumulation on small, fast-response basins. Basin characteristics are easily as important as the rainfall characteristics for determining the nature of the runoff". In addition, the conditions creating flash floods differ, even in the same location. For example, an unusual situation occurred with the 1997 Fort Collins, Colorado, flash flood. In this event, rainfall rates increased rather than decreased at the end of the storm. Thus, rainfall timing as well as intensity can be critical, and work must continue to understand general relationships using specific events as input (see Baldini et al., 1995 for an example).

Significant improvements have been made both in the recognition of the range of data needed to make accurate forecasts and in the technology to obtain relevant data. With respect to the former, data on rainfall intensity, basin characteristics (including current soil moisture information), and hydrologic response must be collected and modeled. With respect to the latter, satellite and radar have facilitated monitoring of precipitation systems, and automated rain and stream gauges provide information in a timely manner (Kelsch et al., 2001). In addition, networks of soil moisture observations are currently providing input to predictions of surface runoff, and improvements in remote sensing of soil moisture will further enhance such predictions (Basara, 2001).

Despite these advances, the complexity of the flash flood environment means that uncertainty prevails. All hydrometeorological predictions are uncertain, partly as a result of the complex systems they attempt to predict and partly as a result of data assimilation problems among the systems involved. We are far from developing a deterministic approach to flash flood forecasts and warnings, even though some hydrologic engineers disagree (Krzysztofowicz, 1995). Indeed, all of the tools used for monitoring the conditions that contribute to flash floods have some measurement errors. Quantification of the related uncertainties is a major task of those involved in hydrometeorological modeling and forecasting (Kelsch et al., 2001).

At the other end of the system is use of the forecast and, particularly, the warning that is issued. A time lag exists between issuance of a forecast and recognition by local officials that a serious flash flood potential exists such that they issue a warning and take the necessary mitigation measures. Yet, time is of the essence, given the nature of flash floods. In addition, the uncertainty that exists cannot be ignored. A few minutes lost in any part of the warning process can have catastrophic results. This is the case over small areas, and as the size of the area at risk increases, uncertainty increases as does the potential for heavy losses. Thus, timing becomes even more important.

Throughout all components of forecasting and warning systems are assumptions that guide our research and pervade our approaches to both developing and implementing the entire system. These assumptions relate to physical systems and their responses, to political systems and their responses, and to individuals and their responses. A critical part of efforts to improve forecasting and warning, then, is continually evaluating the validity and accuracy of these underlying assumptions. For example, models involving moving from large-scale predictions to small-scale rainfall models must also include a means of testing the hypotheses and assumptions upon which the original predictions were based (Kelsch et al., 2001).

Effective warnings start with monitoring and forecasting, and move through decision-making and message dissemination, to preparedness and mitigation. Thus, this is a multi-disciplinary effort that starts with evaluating the tools, methodologies, and models utilized in detecting and forecasting events and continues through analysis of all components of the warning system, including responses by officials and the public. On-going efforts at improving the knowledge base and performance of each of the components are essential to reducing the uncertainty that prevails in forecasts and warnings. Evaluations of successes and failures of models, forecasts, and warnings, will also lead to improvements in the systems.

3.2. *Applying knowledge directly to loss reduction*

A great deal of research has been undertaken on various aspects of flash floods, from a variety of disciplinary perspectives. Much of this research is very applied in nature. Still, as it is across much of the hazard research community, knowledge is not readily being translated into operational changes, and experience is not easily finding its way into policy revisions. For instance, the progress that has been made in estimating and modeling precipitation rates and basin responses is only useful if the data can be quickly and readily translated into accurate, useful forecasts. Similarly, the losses incurred in the November, 1999 flash floods in Southwestern France might have been avoided if the lessons learned in other places that chose to develop in flood prone areas had led to land-use regulations restricting such development.

Flash flood researchers, whether physical or social scientists such as those at the NATO Institute, continue to address the complex social, economic, and scientific problems that flash floods present. At the same time, officials at all levels and in many positions have searched for answers to questions they must address. Research needs to be applied to loss reduction. For instance, an important question for both researchers and practitioners is how the information used in detection of a problem and in forecasting it is related to response. After an event, was the end result of the detection, forecasting, and warning elements merely a series of detailed color pictures to be evaluated in numerous post-event studies with finger-pointing at agencies or individuals, or did these elements truly reduce losses?

Certainly, research and application sometimes come together, but often they do not. A useful example of this relates to mitigation. It is recognized by all involved that mitigation is important, but specific information documenting associated benefits and costs is lacking. Systematic evaluations of the effects and effectiveness of mitigation measures are needed (Montz, 2001). This fact was recognized by participants in a flash flood symposium in 1986 evaluating lessons learned from the 1976 Big Thompson Flood that killed 140 people in Colorado (Gruntfest, 1987) and was reiterated 10 years later at the subsequent symposium (Gruntfest, 1997; Krimm, 1997). This information is crucial to local officials as they work to reduce vulnerability within the context of local development goals. The flash flood problem is complex. Catastrophic flash floods are more than meteorological events. They involve hydrology, topography, land use, timing and numerous other factors. Since catastrophic flash floods are rare, each one has its own set of physical, social, and institutional characteristics. Still, we need to direct ourselves to applying what we know and to learning from experience, if we hope to make progress.

No answers are immediately forthcoming; rather this is an important focus for those involved in flash floods, whether researcher or practitioner. On one hand, efforts might be directed to discerning how we measure success, perhaps in the form of a model that accurately predicted a given event. Alternatively, success might be found in a set of mitigation measures or in response to a warning that resulted in significantly lower losses than would have occurred without implementation of mitigation measures. Comparison of losses between events at a place might be useful to this end (Weaver et al., 2000).

On the other hand, asking how we know that we are heading in the right direction might be the focus. To a certain extent, this relates to the discussion of assumptions in the previous section, but it goes beyond that to delve into what exactly the goals are, under what conditions, and for whom. For example, Automated Local Emergency Response in Real Time (ALERT) systems have made significant strides in flash flood warnings, having been used to move beyond detection to warning (Stewart, 1999). The flood detection technology that was available in the late 1970s provided the initial impetus for the ALERT system, which has since evolved into a decision support tool (Stewart, 2001). In addition, the data obtained through ALERT systems have been used for other purposes, including drought detection and reservoir management (Gruntfest, 1998). Thus, success can be measured from a number of perspectives, and it is a challenge for researchers to evaluate how they would measure success and how they know they are heading in the right direction.

3.3. Focus on social science links

Physical science and engineering advancements are absolutely essential to coping with flash floods, particularly as hydrologists, meteorologists, and others strive to understand the factors that will help us distinguish flash floods from other severe events. However, these advancements will only make a difference if the recognition and understanding of warnings, warning response, and risk communication are increased. The hydrometeorology of flash floods is very complex and remains shrouded in uncertainty. Yet, even given this, these more technical aspects are better recognized compared to what is known about people's behavior.

Exposure to flash flooding and, therefore vulnerability to loss, continue to increase, even as our ability to forecast events and warn areas at risk increases. What this suggests is that it is absolutely imperative to direct efforts toward defining vulnerability and understanding the social, political, economic, and perceptual factors that are at work. Vulnerability is increasing because of increases in population, and we also know that this varies from place to place, due to a number of factors (Gruntfest and Handmer, 2001). Further, different segments of society are not equally vulnerable: sometimes resulting from factors under their control, sometimes from factors beyond their control; sometimes in a predictable manner, sometimes in a manner that is not so predictable (Blaikie et al., 1994; Tobin and Montz, 1997). It is difficult enough to gain a sufficient understanding of the situation in one socio-economic context, in large part because the entire system is so dynamic. Making generalizations that can be useful to planners and emergency managers is even more difficult, partly because of the ever-changing system and partly because of our lack of knowledge.

Two examples are used to illustrate the need to focus on social science links. At one scale is individual action and perception of risk to flash flooding. Presumably, technical advancements lead to earlier and more accurate warnings. Yet, how will people respond?

The last major research on the warning process to include detection and response is 25 years old (Mileti, 1975). For some hazards, there have been significant improvements in warnings such as in nuclear power or hazardous materials (Mileti, 1999). For other hazards, little progress has been noted. A review of warning systems research completed in 2000 calls for a national warning strategy:

> The nation needs to develop a comprehensive model for warning the public, provide it to local communities along with technical assistance, and make the degree of protection provided by warning systems for all citizens more equitable (Sorensen, 2000, p. 123).

Sorensen goes on to point out that improved technology alone will not improve warning systems; the warning dissemination process must be improved as well (Sorensen, 2000). Perhaps it is time to ask different questions or come at the issue from a different perspective. Whatever the case, a better understanding of how people interpret and react to warnings (or do not), and of whether or not they appreciate what a flash flood can do and how quickly it can occur is essential. This can be garnered from perception studies, but it might also be useful to look at economic models that track investment trends and willingness to accept risk. More likely, a combination is needed. Again, there is relevant literature on hazard perception, but flash floods may be sufficiently different from other events that new strategies are required. Similarly, much has been written about the problem of "crying wolf" (see Breznitz, 1984 for an example), and local emergency managers worry about giving false alarms (Mileti, 1999). However, repeated alarms with no event at all and near-miss warnings (where a warning was issued and the event occurred elsewhere or was not as severe as originally forecast) may present different situations. Indeed, near-miss false alarms may be useful training opportunities for the local emergency management community. Still, the possible negative effects of such warnings among the population at risk are not well understood (Weaver et al., 2000). In the United States, National Weather Service policy calls for the false alarm rate for forecasts to be cut in half. Is this policy appropriate? Are people less likely to respond to a warning if the previous warning did not result in a serious event? No research has evaluated this question. In its absence, hearsay evidence should not direct Weather Service policy.

At another scale, the tensions between hazard management and economic development must be addressed. Explaining risk to individuals is certainly a significant issue, but so too is the need for community leaders to understand risk. Pressures for economic development exist virtually everywhere, but the risks are not evenly or widely distributed. When community leaders choose to expand development in areas subject to flash floods, or on hillsides that exacerbate runoff contributing to flash flooding, one wonders if they fully understand the level of risk that they are accepting and the impact an event will have on the community. When tourists are encouraged to camp by streams with great flash flood potential or when "caving" takes tourists into potentially dangerous places, money is made and the risks are voluntary. This was an issue with the 1999 floods in Southwestern France, after which the Environmental Minister called for an inquiry focusing on changes in drainage brought about by building in hazardous areas (Litchfield, 1999). Similarly, flash flood mitigation takes an investment of time, money, and expertise, at the very least. Little is understood about the conditions under which mitigation has been embraced and implemented by community officials, and those where it has been ignored or put off.

These are but two examples of the kinds of links to social science that are necessary if we are going to reduce vulnerability. Physical science and technological advances are critical, but experience has shown that a similar effort that focuses on understanding social systems is equally necessary.

3.4. Sustainable and long-term mitigation policies

Economic development and hazard management are not mutually exclusive, though they are frequently seen as such. Mitigation efforts will only be successful if they work with, rather than against, community goals and priorities. Economic growth is not sustainable if it is devastated by a flash flood event. Similarly, mitigation measures that stymie a community's vitality will hardly be acceptable. Unfortunately, the prevailing attitude among many local officials appears to be that mitigation is anti-development. It is important, then, to change that attitude to one that focuses on sustainability based on the argument that community development can only be sustained if it is not compromised by disaster. This is much easier said than done but is something that is necessary with regard to all natural hazards. In addition, as noted earlier, flash floods are different than riverine floods, and thus what is applicable to one may not automatically be applicable to the other. Flash flood mitigation requires a different way of thinking.

This different way of thinking might be divided into two components: one based on multiple objectives and the other based on a long-term outlook (Tobin, 1999). With regard to the former, new approaches to community development are required that are multi-objective and multi-disciplinary (Brilly, 2001). At the risk of over-simplification, this would require creativity in developing and enforcing flash flood mitigation policies that do not unduly compromise economic growth, while also insuring that vulnerability of all groups is decreased. Some of this relates to land-use planning and management, some to engineering, and some to hydrometeorology. Thus, where there are multiple objectives, there will have to be multiple disciplines involved. As an example, Fort Collins, Colorado undertook a flash flood mitigation program based on a 1989 master plan. This program included relocating structures, making bridge and drainage improvements, and promoting public awareness (Grimm, 1998).

Because flash flood problems will not be solved over the short term, it may be necessary to look to the eventual outcome of mitigation strategies rather than their immediate effects. Currently both public and scientific thinking are focused on the near future rather than on the longer term. However, both are necessary—requiring a greater focus on the longer-term. In particular, it will be necessary to determine how to measure success from all perspectives (based on the multiple objectives and multiple disciplines involved) and to develop benchmarks at which to measure our progress. Using the Fort Collins example with actual and potential losses from the 1997 flood, it is estimated that the benefit cost ratio of the mitigation plan is 1.67–2.91, indicating a significant payoff after <10 years (Grimm, 1998).

Consideration and implementation of mitigation policies are all taking place in dynamic physical, social, and economic environments, that vary from place to place and from time to time. So far, that has hindered a multi-objective, long-term approach. However, since current approaches are not working, as measured by losses that continue to mount, this must change. "In a changeable world, the best solutions from the past are not the best for the future and we ask for more flexible and adaptable solutions" (Brilly, 2001, p. 103).

4. Conclusions

Because of the rapidity with which flash floods occur and the power that they carry, flash flood experts have long recognized that warning is the key to reducing vulnerability. To that end, much progress has been made in developing and improving detection and forecasting systems through incorporating real-time data as well as models. Still, losses are increasing, as development in flash flood prone areas continues and warnings are not always accurate, timely, or are not heeded. The combined experience, knowledge, and wisdom of an international group of researchers who met in Ravello, Italy in 1999 led to the recognition that, while we are better able to identify hazardous situations, the amount of uncertainty that surrounds flash floods and their impacts remains large. Further, a multi-disciplinary effort is required to reduce that uncertainty. A focus on advances in technology alone or on defining vulnerability and developing appropriate mitigation strategies alone will not be sufficient to reduce losses. Strategies that are comprehensive in their focus are required. In this respect, flash floods are no different than other hazards, as calls for improved management cut across the spectrum.

Reducing vulnerability to flash floods requires a different approach than reducing vulnerability to most other natural hazards, particularly other floods. With flash floods, deaths and property losses per unit area can be very high and flood mitigation strategies alone are not sufficient. Flash floods require a different way of thinking, based on recognition of a system that begins with detection of a rain event as having potential to cause a flash flood and ends with an informed public and losses that did not occur because of mitigation measures. Of course, there is a great deal that we know and, more importantly, that we do not know between the beginning and end of the system. For the most part, research efforts, whether basic or applied, have dealt with one or another of the components of the system, and we have learned a great deal. Still, uncertainty about individual elements of the system remains high.

Research that incorporates all aspects of the flash flood equation is required to reduce vulnerability to flash flooding. Flash flood mitigation has too often been seen as a choice of high technology approaches to prediction and warning systems, with some inclusion of evacuation. Instead, a more holistic approach is needed that includes as part of the mix the problem of increasing risk and vulnerability through, for example, land-use decisions, in addition to prediction and warning systems. Thus, natural scientists and social scientists must work in concert to identify how changes in one area will filter through the system. This is not to suggest that one or the other focus be emphasized but rather that future work in both areas be centered on reducing vulnerability through a more integrated approach. Such a recommendation cannot be implemented easily because it requires a new way of thinking by all involved. As a result, opportunities are needed for those involved in flash flood research and application to come together to set research agenda and to work through issues that will arise, of necessity, when different disciplines with different approaches try to work together.

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