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Costs and benefits of early warning systems

David Rogers and Vladimir Tsirkunov

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Introduction

Cost-benefit analysis, used with care, is a useful tool to help translate spending into effective disaster prevention. World Bank (2010), in their comprehensive report on Natural Hazards, Unnatural Disasters, identify three specific spending items desirable for disaster prevention – early warning systems, critical infrastructure and environmental buffers. Hazard warnings are of great benefit because early warnings save lives and property. Critical infrastructure reduces loss of life and property during and after a disaster. What is critical, however, depends on the situation and the hazard. Bridges and roads used as evacuation routes in the path of hurricanes, schools located above flood waters that provide shelter, hospitals that are earthquake resistant are all examples of critical infrastructure related to specific hazards and disaster risk reduction. Investment in this infrastructure provides ancillary benefits which offset the costs; in this case, everyday transportation, education and health care. Environmental buffers offer protection from hazards within physical limitations such as dense vegetation for flood and erosion control or coral reefs and sand dunes to protect against storm surges. It is generally cheaper to protect than restore them; although what to protect is not always obvious.

While evidence on the costs and benefits of disaster risk reduction consistently shows that investment in early warning systems can save lives and help protect property, most preventive measures focus on critical infrastructure to prevent disasters such as flood control systems, strengthening building codes, construction of shelters, and protecting environmental buffers. Often these preventative measures serve different people in different ways. Investment in critical infrastructure may not directly improve the security of the poorest that may be displaced by construction projects to more marginal areas. Appropriate investment in all three areas, early warning, critical infrastructure and environmental buffers, is likely the best approach since neither major infrastructure investment in flood control measures, nor a flood early warning system can avert a disaster completely. Together, they can, however, greatly reduce loss of life and livelihoods. Thus substantial benefits of early warning are often best realized when coupled with infrastructure and other preventative investment. In Hong Kong, for example, housing improvements mean that sheltering the population at home is now the best action to take in response to a tropical cyclone. Here, early warning ensures that people have the time to return safely to their homes utilizing an adaptive public transportation system that is responsive to the warnings. Timely warnings, effective communication and response permit the Hong Kong economy to rebound quickly from such hazards (Box I).

We know that we are capable of reducing the death toll even in poor countries; moving food averts a famine despite droughts and early warning reduces deaths from storms and floods. However, in general, the evidence suggests that we tend to spend more on relief than on prevention and that this is a public preference despite the evidence that indicates investment in prevention is more valuable than spending on relief (Healy and Malhotra 2009). When spending on preventative measures does occur, it is often biased against those that have little economic clout and political voice with the effect that large protective infrastructure investments often result in the dislocation of the poor residents to other risk-prone parts of a city (World Bank 2010). In this case, early warning systems rather than protective infrastructure may serve the poor better.

Box I. Tropical Cyclone Warning Service in Hong Kong

The tropical cyclone warning service of the Hong Kong Observatory (HKO) has evolved into a numbered system: the Standby Signal No. 1 is issued whenever a tropical cyclone is within 800 km of Hong Kong and may affect the territory later; Signals No. 3 and No. 8 warn the public of strong and gale/storm force winds in the city respectively; Signal No. 9 signifies increasing gale or storm force winds, while No. 10 warns of hurricane force winds. In view of the stringent building codes in Hong Kong, home is generally considered the safest place for people to take refuge from a tropical cyclone. When Signal No. 8 is issued, the HKO advises the public to stay home or return home. Over time, a tradition of societal response has emerged in which businesses and schools would close down when the tropical cyclone gale warning signal No. 8 is hoisted.

The tropical cyclone warning system has been in use for many years and the public is already familiar with it. Together with the well-coordinated response actions taken by relief agencies, the system has proved very effective in reducing the loss of life (graph below) and property due to tropical cyclones.

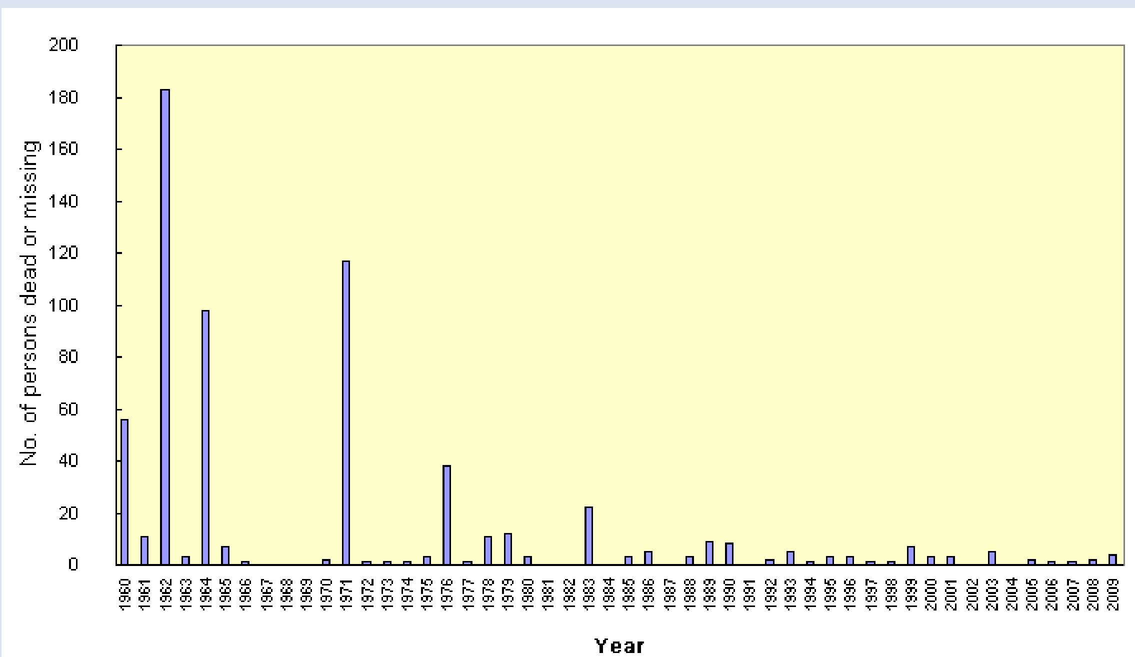

Figure Number of people killed or missing due to tropical cyclones in Hong Kong since 1960

Wai and Wong, 2010

How do we decide on the appropriate investment in preventative measures? Cost-benefit analysis says that an investment whose benefits exceed the costs should be undertaken, and if there are competing proposals, the one with the highest benefit to costs should be preferred. The dilemma is that it is necessary to value the lives saved in order to arrive at the right investment choice. One approach, proposed by Cropper and Sahim (2009), calculates the reduction in injuries and deaths in terms of quality-adjusted life years (QALY). Then the cost of prevention minus the non-health benefits of prevention can be divided by the QALYs saved to compare cost per QALY across all policies to encourage consistency in decision-making (World Bank 2010). This approach would be particularly useful in evaluating the effectiveness of early warning systems since they have the biggest impact in reducing loss of life and injury. Not counting the value of lives saved implicitly puts a zero value on life and undermines prevention. For example, only by including the value of lives saved in Turkey, did preventive measures such as earthquake strengthening of apartments and schools pass the cost-benefit test (World Bank 2010).

In the following sections we describe the benefits of early warning; we then consider in more detail the costs and benefits of warnings where false alarms and poor decisions can incur large costs to individuals and governments; and finally we provide some examples of cost-effective warning systems.

Early Warning Systems

Early warnings give people time to flee from a flash flood, tornado or tsunami; enable local authorities to evacuate or shelter large numbers of people in advance of a tropical cyclone or hurricane; provide information on the occurrence of a public health hazard; and enable a faster response to problems of food and water insecurity. Warnings issued well before an event also enable people to protect some property and infrastructure. For example, reservoir operators could reduce water levels gradually to accommodate incoming flood waters; local authorities could position equipment for emergency response; aid agencies can mobilize sooner; people could shutter windows and reinforce rooftops; hospitals could be prepared to receive more patients. In general, the longer the lead time, the greater amount of property and infrastructure that can be protected. However, with longer lead times comes greater risk of false alarms and incurred costs. For example, reducing water levels if the predicted flood waters do not replenish the reservoir may result in significant social and economic losses in terms of the supply of hydroelectric power or potable water.

There is no doubt that effective early warning systems have substantially reduced deaths and injuries from severe weather events. Mortality in the United States declined significantly over the years because its early warning systems for recurring hazards such as lightning, floods, storms, and heat waves are continually improving: mortality fell by 45 percent and injuries by 40 percent in 15,000 tornadoes from 1986 to 1999 thanks to more timely warnings that enabled people to take shelter (Teisberg and Weiher 2009). Early warnings of flooding risk have been shown to be effective in reducing flood-related deaths (Malilay et al. 1997). For example, there is a difference between the 1992-1994 flooding along the Rhine and Meuse rivers and the 1995 flooding along the same rivers (Estrela et al. 2001). The two floods had similar characteristics; both were caused by persistent heavy precipitation. Ten people lost their lives and over US$900 million in damages occurred during the first event, while the economic cost was reduced by almost a half and no lives were lost during the 1995 flood due to awareness and behavioral changes.

Heat health warning systems[1] have proven to be particularly effective in reducing mortality (Ebi et al. 2004, Rogers et al. 2010). In an evaluation of the system put in place in Philadelphia in 1995, it has been estimated that a warning saved 117 lives over a three-year period (Ebi and Schmier 2005). Météo-France has pioneered the development of early warning systems for meteorological hazards using vigilance charts with color-coded hazards according to severity for each of the 100 French departments (administrative regions). However, despite having a good forecast of the extreme heatwave that struck Europe and France, in particular, during August 2003, the health care system was ill prepared and there were major public health consequences (Rogers et al. 2010) with between 50 000 and 70 000 extra deaths during a 16-day period throughout Europe. About 15 000 of these occurred in France alone, corresponding to a 60 per cent increase in expected mortality in France (Fouillet and others, 2006a). This led the French Institute for Public Health Surveillance (InVS), in close cooperation with Météo-France, to define and implement a heat health watch warning system based on bio-meteorological indicators (Box II).

The impact of this National Heat Wave Plan (NHWP) was evaluated during the July 2006 heatwave, which happened to be the second hottest month in France (since 1950) only three years after August 2003. During these 18 days of heat, the NHWP was exercised fully, including local care to elderly or sick people and daily health advice in all media. Two thousand extra deaths were observed, showing that additional deaths cannot be fully eradicated. Nevertheless, the detrimental effect of the heatwave was reduced significantly when compared with the effects of previous similar events such as in 1976 when there were 9000 additional deaths.

An estimate of the number of deaths avoided is important to determine the overall benefit of the interventions. A forecast model of the expected additional deaths, based on a regional 10-day running temperature mean, has been tested and validated by the French National Institute of Health and Medical Research (INSERM) in collaboration with Météo-France. This suggests that about 4 000 premature deaths were avoided during the 2006 event, most of which were probably due to public awareness and the NWHP (Fouillet and others, 2006b).

[1] A heat health warning system combines bio-meteorological indicators of the human impact of exposure to high environmental temperatures with information on the vulnerability of the population. Environmental temperature and exposure thresholds are tailored to specific geographical regions and people. The systems forecast heat waves several days ahead providing warnings to the vulnerable population, the medical services and others to take preventative actions by reducing exposure, increasing surveillance of the most vulnerable, preparing medical and other facilities for larger case loads.

Box II Heat Health Warnings

The warning system operates from 1 June to 31 August (level 1, seasonal surveillance period). When the alert criteria are fulfilled, the departments declare a new action level (level 2). A third level, which results in maximum mobilization, is implemented if the impacts of the heatwave overwhelm the health system or include power cuts, drought, management problems in funeral centers or heavy air pollution (Josseran and others, 2009). The alert system aims to give the public authorities three days' prior warning that a heatwave may occur, in order for the National Heat Wave Plan (NHWP) measures to be put into operation (Pascal and others, 2006). The preventive measures are aimed at modifying the behavior of people, health institutions and health authorities with regard to high summer temperatures. They include television and radio spots, special assistance to people at risk (many of them being previously registered at their town halls), or facilities to access clinical information on recent morbidity or mortality.

This level of cooperation between the health and meteorological services, led by the health sector and where the meteorological warning works as a "trigger" for local action, is a good example of the way that the health sector can work effectively with the climate community to support operational warning and response systems.

Several lower income countries with recurrent disasters like Bangladesh and Cuba have significantly reduced mortality by developing effective early warning systems (Golnaraghi 2010). Cuba's Tropical Cyclone Early Warning System is credited with reducing deaths dramatically for weather-related hazards such as tropical cyclones, storm surges, and related flooding: five successive hurricanes in 2008 left only seven dead. Gustav, considered to be the strongest hurricane to hit Cuba in the last 50 years, resulted in no fatalities although more than 100,000 homes were destroyed. The absence of fatalities was thanks to an early warning system and an effective response, enabling the people at risk to evacuate quickly to emergency shelters. Similarly in Bangladesh, where despite continuing large financial losses, early warning and response has dramatically decreased the number of lives lost due to cyclones in recent years (see Box III).

Box III Bangladesh: The Antecedents of Lives Saved (from World Bank 2010)

Cyclone Sidr was first observed southwest of the Andaman Islands in the Bay of Bengal six days before it made landfall on November 15, 2007. Tracking its path and growing strength, the Bangladesh authorities had time to prepare a well rehearsed response: they issued warnings and activated 44,000 volunteers who helped evacuate roughly 3 million from their homes and accommodate 1.5 million in shelters. Few were surprised and unprotected when Sidr hit, but its immense force was devastating. The category 4 cyclone (5 is the most severe) with a 1,000 kilometer diameter and winds up to 240 kilometers an hour whipped up 5.5 to 6 meter waves that surged over embankments designed to withstand 2.5 meters. Sidr's forces were moderated when passing over the Sundarbans, a large wetland of mangrove trees, but such wetlands have diminished over the years, and vast unprotected areas were severely damaged. Rescue and relief efforts began immediately after the cyclone abated. The 12 worst affected districts, though less densely populated and poorer than the national average, had 18.7 million people: 55,000 injured, and 4,400 dead or missing. The government estimated that assets worth $1.16 billion were damaged, almost all in housing and other infrastructure. Losses of $517 million were expected. But it could have been far worse if the country had not learned from earlier tragedies.

False Alarms, Costs and Benefits of early Warning

To fully appreciate the cost-benefit of early warning systems, we must consider the overall operational cost of the system, the societal and economic losses due to false alarms and the societal and economic savings due to timely action. These data are needed to properly assess whether and where early warning systems should be established. To be effective, the four elements of the warning system must co-exist: risk knowledge; monitoring and warning service; dissemination and communication; and response capability. If any of these elements is missing or poorly developed, the overall system fails. Prediction alone is insufficient for effective decision making to reduce disaster risk. The strategy for effective and timely decision-making must be known. This includes determining what information is needed, how predictions will be used, how reliable the prediction must be to produce an effective response, and how to communicate this information and the tolerable prediction uncertainty.

Timely action reduces loss of life and property damage. However, decision-makers must also understand the expected consequences of taking action, in terms of the probability of false and missed alerts, the cost savings due to mitigation actions and the cost of a false alert (Grasso 2007). Communicating the early warning and the uncertainty level of the information to users is critical (Grasso et al 2007), otherwise there is a high risk that warning information will be ignored or misused potentially resulting in significant societal and economic costs (Sarevitz et al. 2000).

While there is evidence of the overall benefit of weather services (Box IV) to society, there are relatively few quantitative estimates of the costs and benefits of specific warnings and subsequent actions. This may account for the difficulty in convincing many governments, particularly in developing countries, of the economic and social value of early warning systems as preventative measures for disaster reduction.

Box IV - Benefits exceed costs sometimes more than 10 times

- An estimate in China in 1994–96 found a benefit-cost ratio between 35 and 40 (Guocai and Wang 2003)
- Meteorological services in Mozambique were estimated to have a benefit-cost ratio of 70 (World Bank 2008)
- The ratio of the economic benefits of improved hydrometeorological information (calculated as avoided losses) to the costs of national hydrometeorological services modernization programs vary between 2.1 to 14.4 for some European and Asia countries (World Bank 2008)
- Benefits of improved weather forecasts estimated for U.S. households exceed the cost of U.S. National Weather Service modernization program more than threefold (Lazo, Teisberg, and Weiher 2007).
- A more recent nationwide survey indicates that the U.S. public obtains several hundred billion forecasts each year, generating $31.5 billion in benefits compared to costs of $5.1 billion (Lazo et al, 2009).

The tolerable threshold for a false alarm decreases as the cost of action increases or when the cost savings due to mitigation decrease. In general, because shorter time scale forecasts are more reliable, the probability of a false alarm decreases as the lead time for the predicted onset of the hazard decreases. However, the shorter lead time also means reduced cost savings due to less damage avoided. Thus there is a trade-off between timeliness, warning reliability, the cost of a false alert, and damage avoided as a function of lead time, which must be modeled to determine the cost efficiency of the outcome (Schröter et al. 2008). A major factor in realizing the benefit is the capacity and commitment to act on the information in the appropriate time and manner.

The costs of the warning system itself may be high relative to the benefit if that system is used solely for infrequent events, such as a flood that may occur once in 200 years. If the damage associated with such a disaster is $2 billion and if the disaster could be prevented by a warning system costing $20 million a year, this would be a poor investment since the cost would exceed the annual expected losses by $10 million per year. Prevention through early warning would only be economical if the event was more frequent, the damage greater, or the prevention cheaper (World Bank 2010). In the present example, we would conclude that the resources could be better spent elsewhere.

In practice, National Meteorological and Hydrological Services rarely make a distinction between the routine operation of providing a daily weather forecasts and a forecast of an extremely hazardous, but infrequent weather-related event. The latter being a special case of the routine activities of the public weather services. This means that the incremental costs of providing warnings of infrequent extreme events are likely to be a relatively small fraction of the costs of providing the routine services. It also means that the staff are continuously improving their skills rather than exercising them infrequently. In addition, further cost efficiencies are possible by developing warning systems that serve multiple uses. The Shanghai Meteorological Bureau of the China Meteorological Administration, for example, has developed a Multi-Hazard Early Warning System (MHEWS), which services the needs of numerous agencies within the municipal government. Significant cost savings are realized over systems that would otherwise be developed separately for each agency (Tang 2009). The system is also extensible, making it possible to add new warning services, such as health forecasting, as they are developed (Box V, Rogers et al. 2010). A regional approach based on the same principles, with several countries developing a common multi-hazard warning system, would also be much more cost effective than individual countries developing their own unique systems. As a minimum, in the case of meteorological hazards, data sharing between countries is essential since these hazards are not limited by geographical boundaries and the burden of cost for observations of these phenomena needs to be shared.

Box V – Shanghai Multi-Hazard Early Warning System

Shanghai is vulnerable to natural hazards, such as typhoons, rainstorms, high temperatures, cold waves, thunder and lightning, and heavy fog. These meteorological hazards may cause urban public emergencies, including traffic accidents and public health emergencies. The municipal response to these hazards requires close multi-agency coordination and cooperation. This has been achieved in Shanghai through the establishment of a Multi-Hazard early warning System, which takes 'Multi-Agency Coordination" as the concept and technical core of the system to enhance the capacity of disaster prevention and mitigation in Shanghai. The Shanghai Multi-Hazard Early Warning System (MHEWS) is jointly supported by the World Meteorological Organization (WMO), China Meteorological Administration (CMA), and the Shanghai Municipal Government (SMG). It is technically led by the Shanghai Meteorological Bureau and the Shanghai Municipal Emergency Response Management Office, and jointly developed by relevant local government agencies. The Shanghai MHEWS integrates diverse advanced technologies to support multi-hazard warning, multi-agency coordination and provides a multi-link to emergency response and rescue activities. The Shanghai MHEWS has proven invaluable in support of EXPO 2010 and will be a critical operational system in support of health forecasting, surveillance and early detection of health threats.

The Shanghai MHEWS consists of six technical components:

1. Early Detection and Monitoring Platform, which includes multi-hazard integrated monitoring, disaster tracking and trend warning;

2. Forecast and Prediction Information Generation Platform, which includes various subsystems involving meteorology, traffic, electricity and power security, agriculture, human health and other related fields;

3. Decision-Making Support Platform, which implements the multi-agency cooperation processes, measures and disaster prevention guidelines;

4. Warning Information Dissemination Platform, which corresponds to the Shanghai municipal emergency warning information dissemination platform;

5. Multi-Hazard Information Database, which provides multi-agency real-time monitoring information collection, disaster information and historical data sharing, as well as disaster impact assessments; and

6. Multi-agency coordination network.

There are three management components:

1. Multi-agency coordination and cooperation mechanisms;

2. Safe community protection system for local communities; and

3. Inter-city and inter-provincial disaster prevention mechanism.

Estimating Cost-Benefit of early Warning Systems

The case for flash floods

Quantifying the cost effectiveness of early warning systems (EWS) is acknowledged to be difficult and is therefore not often undertaken. One problem is that factors other than the destruction of property and the number of deaths are seldom included in analyses, and it is often not possible to determine reliably avoided losses (Glantz 2004).

Schröter et al. (2008) have assessed the effectiveness and efficiency of early warning systems for flash floods for small river basins. Their analysis is informative for the development of optimal alerts through the analysis of the trade-off between the benefits of an increased lead time and the simultaneous decrease of warning reliability. Their approach considers that the increase in lead time provides valuable time for the completion of preventative measures, whereas the decrease of warning reliability will cause economic loss in the case of a false alert. The methodology has been applied to two basins in Austria and Spain.

For the assessment of EWS effectiveness, they linked the reliability of the forecast to the economic benefit as a function of warning lead time. The forecast reliability is determined from an analysis of an ensemble of flood forecasts, which describes the uncertainty due to precipitation forecast model parameters and model structure. The economic benefit results from avoided damage through use of the EWS.

Flood forecasting, like most hydrometeorological forecasts, involves a considerable uncertainty because knowledge of the future state of the atmosphere and the state and behavior of the hydrological system is still limited. An integral measure of the reliability of the forecast and warning is based on an interpretation of flood forecast errors obtained from analyses of past events. The information about forecast errors is transferred to a measure of warning reliability as a as function of lead time (Figure 1).

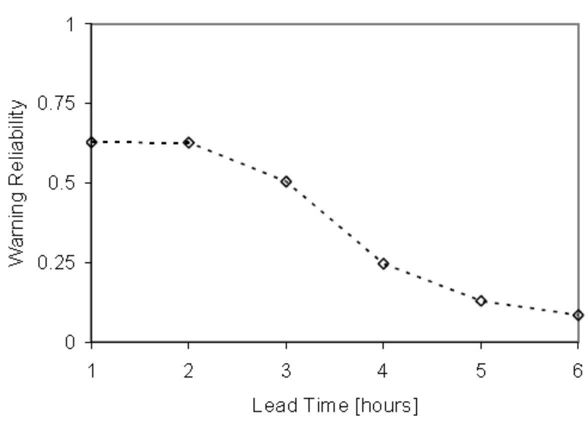

Figure 1Warning Reliability as a function of lead time (Schröter et al. 2008)

Determining the ability to reduce flood damage is based on a survey of users. The most important question for assessing the benefit of an alert is “Supposed you receive an alert some time before a flash flood, by which percentage could you reduce flood damage?" (Schröter et al. 2008). Their results show a correlation between preparedness and the effectiveness of mitigation measures. In the case of a flash flood, a twelve-hour lead time provides a potential 60% reduction in damage, whereas a one-hour lead time results in a 20% reduction (Figure 2). The size of the triangles is a measure of the frequency of a certain answer to the questionnaire. While the sample size is relatively small, it serves the purpose of demonstrating that there is an obvious correlation between preparedness and effectiveness of mitigation measures.

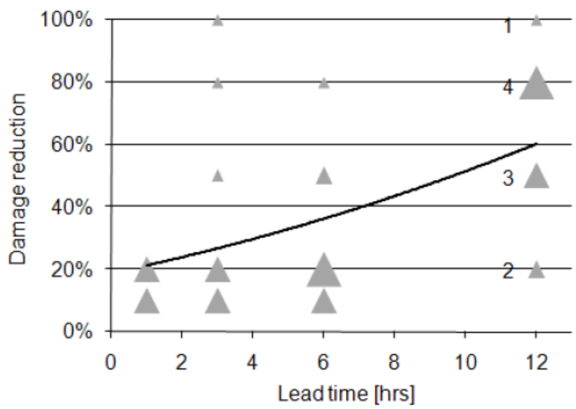

Figure 2. Damage reduction as a function of lead time (Schröter et al. 2008)

Figure 3, also taken from Schröter et al. 2008, presents the Warning Expectation as an indicator for the optimal alert in a general form. With respect to the left axis, the warning reliability curve is drawn as introduced above. Avoidable damage as calculated from the regression line and the comparative risk analysis is drawn with respect to the right axis. According to this the potential damage reduction decreases continuously for shorter warning lead times. The line in the lower part of the graph introduces mitigation costs in terms of lost net value of production (the corresponding values have been scaled with a factor of 10). This curve indicates the cost per hour that arises if the active persons stop productive work and turn to preventive measures.

In view of the considerable costs in terms of lost production associated with an alert, there is good reason to reflect carefully about triggering an alert for a flood event which is still uncertain to occur. The expectation of an alert is defined as the product of the warning reliability and the avoidable damage. The resulting curve, with units € per alert, is given as a bold line in Figure 3. Warning expectation is not constant but changes with lead time. The maximum of the warning expectation curve defines the optimal point of time for releasing an alert with respect to reliability and consequences (Schröter et al. 2009). In practice, this is time where a "watch" becomes an active "warning".

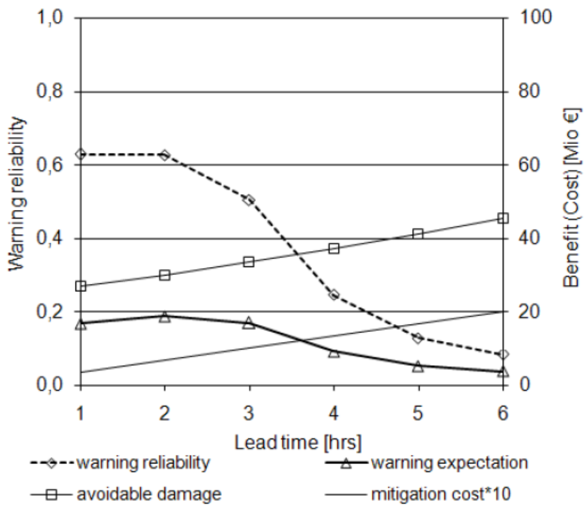

Figure 3. Warning expectation as an indicator of optimal alert in the Besòs basin (Schröter et al. 2008)

A comparison of structural and non-structural flood protection strategies reveals some of the complexities associated with preventative measures for disaster reduction (Table 1). In the case of Polders, construction on the Elbe returns economic benefit whereas the same construction on the Odra River under less favorable conditions returns no economic benefit (Schröter et al. 2008). Local measures showed significant benefit, but flood retention basins failed to meet the economic criterion of a benefit to cost ratio of at least 1. In comparison the benefit to cost ratio of the EWS is compelling. Thus the combination of local protection and early warning appears to be the most efficient combination in this case (Schröter et al. 2008).

Table 1 Comparison of structural and non-structural flood protection strategies including Early Warning Systems (EWS) (After Schröter et al. 2008)

	Benefit-Cost Ratio			
Measure	min	mean	max	Source
Polder use (Elbe)	2.20	4.00	5.80	Förster et al. 2005
Polder use (Odra)		0.10		Gocht 2004
FRBs		0.50		Mertz & Gocht 2001
Local Measures		5.20		
EWS	2.60	4.60	9.00	Schröter et al. 2008

The case for El Nino - Southern Oscillation

Agricultural productivity in many parts of the world is linked to the variability of the El Niño-southern oscillation (ENSO), causing flooding some regions and droughts in others. Early warning systems for climate disturbances can avert agricultural disasters by helping farmers alter their crop decisions, such as growing drought resistant crops or water consumptive plants, or altering planting times. Mexico is particularly sensitive to ENSO-related climatic disturbances. Early warning enables Mexican farmers to make more informed decisions resulting in a positive impact on crop production, enhancing food security, farmers' incomes, and social welfare. Adams et al. (2003) assessed the economic consequences of climate variability associated with various ENSO phases, modeling regional crop yield sensitivity for key crops using a crop biophysical simulator. The value of a forecast was then measured by the expected increase in economic benefits due to changes in cropping patterns, production and consumption arising from yield changes under each ENSO phase forecast. These economic estimates were derived from an economic model of Mexican agriculture. The value of the ENSO information depends on its accuracy in terms of predictions of the weather consequences of each phase.

The economic model used was a stochastic, price endogenous, mathematical model that represents agronomic and economic conditions in a five-state Mexican region. The model depicts agricultural behavior across the three ENSO phases and provides the basis for calculating the value of information. Adams et al. (2003) estimated the benefits of an ENSO early warning system for Mexico is approximately US$ 10 million annually, based on a 51-year time period of ENSO frequencies assuming a forecast skill of 70%. This value translates into an internal rate of return for such an early warning system of approximately 30%. The values for higher skill levels are correspondingly higher.

The case for Landslides

In many regions of the world, landslides cause billions of dollars of damage and often imply significant death rates (Keefer and Larsen 2007). Landslide early warning systems (EWS) are an important tool to reduce landslide risks, especially where the potential for structural protection measures is limited. Colombia is one of the particularly badly affected countries due to predominantly rugged terrain and tropical rainfall conditions. In many areas, landslide hazard zones overlap with residential zones and infrastructure. Hundreds of people have been killed by landslides and debris flows in the past. Most recently, multiple slope failures and landslides destroyed major parts of population centers in June 2006. These recurring events are therefore a serious threat to life, welfare, and local economy (Huggel et al. 2010). Early Warning Systems are therefore important to reduce landslide risks, and in particular, avoid casualties and minimize the evacuation costs. However, design, implementation, and successful operation of a landslide Early Warning System is complex and has rarely been achieved. A critical problem is uncertainties related to landslide triggering conditions, in particular, estimates of rainfall (Huggel et al. 2010), which are critical for decisions on issuing warnings or ordering evacuation. A threshold for landslides in the Combeima valley of Columbia was estimated based on rainfall records and observed landslides. By modeling the actual early warning system, Huggel et al. (2010) were able to determine the costs and benefits of different scenarios: 1) damage to buildings and evacuation costs when a landslide occurs; 2) no cost when there is no landslide and no evacuation; 3) damage to buildings and loss of lives when there is a landslide but no evacuation; and 4) costs when there is no landslide but the population is evacuated. Their results suggest that a linearly increasing rainfall observation error implies an exponentially rising cost due to landslides mostly associated with evacuation costs when a landslide does not occur, and that this information can be used to find improved cost-benefits for rainfall measuring stations. Furthermore they investigated uncertainties related to the rainfall landslide-triggering threshold, which is typically a key element for evacuation decisions. They found that an increasing adjustment of the threshold with increasing rainfall observation error is useful to minimize losses, and that the range of adjustments varies with the local rainfall observation quality.

Conclusions

It is self-evident that early warning of a hazard is useful to take timely action to protect lives and property, and that early warning is a basic component of any disaster risk reduction strategy. However, we do not often consider the reliability of the warning and the potential costs of taking inappropriate action. Cost-benefit analysis of a warning system enables us to determine the optimum time for action and helps to refine *a priori* the decisions that need to be made when warnings are issued. We can also use the analysis to identify where additional spending could be used to reduce false alarm rates by improving hazard forecasts or, if this is not possible, to quantify the cost of protecting vital assets through appropriate infrastructure investment. Despite their utility, there are very few quantitative assessments of the cost-benefit of early warning systems, which may account for continuing underinvestment in warning systems in many places, particularly developing countries with competing needs for scarce resources. In most cases, for meteorological hazards, the quality of the forecasts for early warning are directly related to the uncertainty in observations, which given the paucity of observations in many developing and least developed countries, is a contributing factor in limiting the effectiveness of early warning systems in these countries.

A detailed assessment of flash flood warning systems in Europe is used as an example to highlight the value of the cost-benefit analysis enabling a realistic estimate of the benefit of action in advance of a flood and how that benefit decreases with increasing but less accurate forecast lead time.. A similar approach could be adapted and used more extensively for other types of warnings. Such a quantitative approach to justify *effective* spending may encourage governments to make greater use of early warning systems. Despite the evidence of the value of prevention, many countries continue to rely on post-disaster relief rather than prevention in the face of natural hazards.

An analysis of the cost of the hazard and the potential benefits may help determine the type of forecast and warning system and response mechanisms that would be most cost effective. For example, costs resulting from flooding can be estimated for various magnitudes of events for various centers. Damage statistics from previous floods are also valuable in establishing the costs associated with such events. Judgment is needed to estimate the benefit of flood forecasting and warning in reducing damages and loss of life. Governments and financial institutions require such information on costs and benefits to help understand where expenditures will reap the largest rewards. Studies and analyses have shown that damage reduction due to forecast improvements can range from a few percentage points to as much as 35% of average annual flood damages. A standard set of flood damage categories relevant to the basin should be developed. When loss of life is a threat, this too should be identified, even though it is difficult or impossible to quantify in economic terms. Other damage categories could include residential buildings; commercial, institutional and industrial buildings; agricultural lands; and infrastructure. Additional costs include temporary relocation and flood-fighting costs. Hazards of all kinds can have an effect on the population and economy of an entire country, and business losses should also be included in the analysis. Developing standard damage categories allows damages to be more accurately estimated for various hazard levels.

A rigorous cost-benefit analysis would require determining the hazard frequency distribution so that the present value of future benefits can be determined. In the absence of sufficient data or analysis, a more rudimentary presentation of costs and benefits may be sufficient to determine the size of the investment that is justified for forecasting, warning and response.

Warning systems are effective when they are accompanied by critical infrastructure – safe evacuation routes, shelters for humans and livestock, secure hospitals, and so forth. The most cost efficient warning systems are those that can be exercised on a routine basis; in the case of meteorological hazards as a part of the public weather service. In addition, even greater benefit is achieved through multi-agency cooperation to develop multi-hazard early warning systems that rely on routine functions to increase their benefit relative to their cost. This is work that has been pioneered by the China Meteorological Administration and the Shanghai Municipal Government with the WMO, and can be adapted for developing as well as developed countries.

Finally one critical step is the willingness to act on a warning and take appropriate individual and collective measures to protect lives and property. The individual's willingness to act cannot be taken for granted. Therefore a completely effective warning system is one that engages its expected beneficiaries by raising awareness and knowledge of risks and ensuring that the actions taken are realistic. Farmers, whose livelihoods depend on a few cows, will likely value those cows as much if not more than their own lives and this must be considered when responses to hazards are developed.

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