global platform for disaster risk reduction

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Issues Briefs

1. GP Working session specific issue brief

Event title	**Multi-Hazard Early Warning Systems: progress and challenges to achieve target G**
Rationale	*~ 500 words* *Why is this topic important and worth a Working/Special Session or High Level Dialogue?* The Sendai Framework for Disaster Risk Reduction 2015-2030, recognises that early warning systems (EWS) play an important role in reducing the risk of death, injury, disease, loss of livelihood and damage to property from disasters. Advance science and technology, real-time observation and monitoring system enhanced hazards forecasting and warning services which contribute to effective EWS. However, not all countries have been able to achieve effective EWS and like the links on a chain, the overall system is only as strong as its weakest link. Still limited access to EW information to the communities and appropriate lack of risk communication results in uneven spread of societal benefits across countries and communities, often missing the most vulnerable. The Sendai Framework urges a paradigm shift towards an impact-based, risk-informed multi-hazard integration approach for multi-hazard early warning systems (MHEWS), disaster risk reduction strategies and government policies. As EWS for specific hazards and consequences have many common elements, the use of a common MHEWS framework enables sharing of lessons learnt, create economies of scale and eventually reinforce sustainability of the system.

	MHEWS provide a common foundation of risk assessment, planning and exercising for hydro-meteorological, geological and biological, as well as human-induced and technological hazards, that ensures an effective emergency response, whether the hazard is frequent and low-impact or rare but high-impact, on timeframes ranging from the immediate to multi-year. It ensures common lines of control and communication in an emergency, including mechanisms for accessing and incorporating situation-specific expert knowledge from diverse sources. Since hazards may be linked or may trigger new hazards, it is necessary that recipients can access hazards information in a common geospatial framework and enough lead time. MHEWS inform people of the potential impacts of impending natural and human-induced hazards on their lives and livelihoods and of actions they could take to protect themselves and minimize impact. To be effective, this approach entails cooperation and coordination between and among stakeholders from all levels, including national disaster risk management agencies, meteorological, hydrological and geological services, scientific institutions, civil protection organizations, intergovernmental organizations, central and local governments, Parliamentarians, civil society, communities at risk and the private sector. MHEWS should engage all relevant actors to increase the effectiveness, efficiency, consistency and utility of warning services. Since different users of MHEWS are exposed to different hazards, have different vulnerabilities and require different information for their responses, an effective MHEWS should be co-designed with each type of user. At the same time, the MHEWS must be practicable and must operate in an emergency situation. Achieving these twin aims requires flexible and diverse services within a common governance framework. Some users look for advice on actions to take, while others have response plans that require information on expected impact, and others find basic hazard information more useful. Some are only interested in low probability, high impact warnings, having protected themselves against more likely hazards, while others are only concerned with high probabilities. The way risk information is communicated should be tailored to users with different levels of disaster risk awareness and understanding. Achieving effective responses to MHEWS requires that users trust the warning enough to act on it. In a world of competing information sources, a user is more likely to trust information from a recognised source with whom they have an established relationship. Achieving this may involve personal contact, careful branding, multiple consistent messaging, use of a trusted intermediary or other approaches.

State of Play and Opportunities	***~ 500 words.*** ***What are the main challenges? What gaps need to be filled?*** A multi-hazard approach to early warning systems ensures that information about hazards and risks is addressed in a shared system using common capacities and procedures to prepare and respond to several hazards. To be effective and user-oriented, policy, institutional arrangement and coordination mechanisms are at the essence. An important challenge remains in providing information on hazardous events that might occur simultaneously, in cascade or cumulative over time. Taking into account potential interrelated effects and informing users on probable cascading hazards and disaster events remains difficult for early warning systems but is considered to be more manageable from a multi-hazard perspective. While steady progress has been registered in the past decades in forecasting, modelling science and information and communication technologies to support early warning, the societal benefits of EWS have not spread evenly and some countries, especially SIDS, LDC and LLDV experience considerable under-investment on EW infrastructure, governance mechanisms and capacities. Communities in remote areas and especially marginalized, vulnerable and special needs groups face accessibility challenges. Transforming data on hazards and risks into timely, meaningful and actionable information and knowledge for multiple users, including different at-risk groups, requires governance mechanisms for inter-institutional coordination and user participation. Co-designing of EWS and warning information co-production approaches aim at addressing each user needs, allowing for segmentation of information and incorporation of targeted impact details to enable protective action. To respond to the needs of all at-risk groups, the assessment of vulnerabilities to disaster risk and coping capacities should consider cultural factors, social processes, indigenous knowledge and power dynamics that drives risk-poverty nexus and create inequalities. Another key challenge on enhancing the potential of EWS to save lives and minimize disaster losses refers to the need to consider them as part of a larger Disaster Risk Management frameworks and therefore fully integrate them in disaster risk reduction policies. Early warnings alone do not keep hazards from turning into disasters. Although current understanding of EWS has highlighted that the capabilities to act and respond upon warning messages are an integral component of a functional early warning systems, their full potential for minimizing disaster impact in human lives and communities' assets lays on their development being addressed in conjunction with

	building anticipatory, absorptive, adaptive and transforming capacities to manage existing risk and prevent the creation of new ones. Early warnings should be seen as a system which considers community perception of risk, social norms, indigenous knowledge, capacities and resources' availability. The end-to-end early warning system for disaster risk management (DRM) is comprised of ten individual elements or systems that work together to create the entire system – a 'system of systems.[1]' The integration of each element with equal strength is critical for the success of the EWS. One weak element can cause failure of the overall system. Within this system of systems, an enabling environment for prioritizing DRR in the development agenda is as important as the community connection response. Solution and action-based approaches, such as forecast-based financing (FbF) has been recently advanced as a mechanism to enable realization of early action potential associated with early warnings. FbF instruments are devised to enable access to funding for early action and preparedness for response based on in-depth forecast and risk analysis. Challenges to scale up FbF programs relate to the current operation modes of the humanitarian system, which is largely focus on response after a disaster occurs while funding for anticipatory actions is scarce. To be an effective dynamic model, Fbf need to be built on robust evidence on the effectiveness of humanitarian early actions and requires an iterative process to understand risks, especially hazards and vulnerabilities, to strengthen forecast skills and to assess impact of the preventive actions supported. Transformations in the humanitarian financial landscape are needed to take forecast-based financing up to scale, while coordination and integration with all DRM cycle measures continue to be essential. Another remaining gap remain operationalize advance science. Advances in meteorological, hydrological and engineering sciences are fast generating a range of new methodologies for forecasting weather and flood events, including ensemble prediction systems (EPS) and new hydrological or hydrodynamic models. However, many of these advanced prediction systems have not yet been incorporated into operational forecast systems. Consequently, operational forecasts have not yet been integrated into decision making processes in order to reduce disaster risks.
Way Forward	***~ 500 words.***

[1] B.Fakhruddin, N. Lomarda and K. Boylan. Total Warning System for Tropical Cyclone.WMO and Tonkin-Taylor

	What innovative approaches should be considered? It's clear that an early warning is not helpful unless it reaches the people who need to act and provides information about its impacts. To respond to the early warning the information need to be understood and internalized by the people. Thus an interpretation and translation of the scientific information is essential. The EWS needs to incorporate users' needs to enable people to visualize the possible scenarios with probabilities of risk to reduce their vulnerabilities. EWS comprises both the systems and processes that enable individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events. Considering the relevance of timely action to reduce risk in this definition, several good models exist globally (e.g. forecast-based financing initiatives). The multi-hazard approach to early warning systems has been promoted as a mean to increase the efficiency and consistency of warnings through coordinated and compatible mechanisms and capacities, involving multiple disciplines for updated and accurate hazards identification integrating monitoring systems on a systems of systems and ensuring compatibility of both local and global data networks. In order to better address increased interconnectedness in disaster risk, MHEWS should look into ways to address the complexity embedded in cascading disaster effects in terms of geography and sectors. To realize the efficiency gains, multi-hazard systems require a carefully designed governance framework that ensures smooth inter-institutional coordination, end-user focus and participation. Feedback mechanism resulting on system improvements are considered essential to maximize the potential of early warnings to minimize disaster losses. For any new forecasts product, there will be lack of communication to receive the warning to the affected people, interpret or internalize the information for decision-making and response. For taking a good decision, the capacity of generation of early warning with sufficient lead-time with an acceptable degree is essential based on end to end early warning framework. Research and development advancement forecast products using ensemble methods have been widely used for operations in many countries. *Policy innovations*

	• *Co-production of warning information*: A shift towards co-production of information implies that end-user change their role from pure users to collaborators and partners. • *Emerging role of social media in the dissemination and verification of weather warnings*: Harvesting of social media and user reports in a 'citizen science/crowdsourcing ' approach are innovative approaches to include 'ground truth' data on impacts. However, this new information sources need to be reliable and require extensive testing, verification and quality monitoring. • *Strengthen institutional mechanism* to regularly consider and assimilate information on slow-onset disasters. The experience of monsoon forum has been highlighted as a powerful policy innovation for strengthened cooperation. Building on this practice of national climate outlook dialogues, the design of multi-layer monsoon forums has been proposed as an effective dialogue among users and producers of seasonal forecast information to understand potential impacts and develop corresponding preparedness plans. This multi-layer schema will ensure that regional, national and local forums are interlinked for knowledge sharing and information exchanges. *Technological innovations* Use technology advances as windows of opportunities to make a critical difference in terms of planning and preparedness on the ground. • *Technical innovations*, especially in information and communication technologies, provide a range of challenges as well as opportunities in warning delivery. • Applications of probabilistic forecasts for operational forecasting and risk assessment. For example, use of meteorological ensembles to produce sets of hydrological predictions increased the capability to issue flood added great value to a flood early warning system. • When communicating warning alerts, predicted events and the corresponding uncertainty, the communicating authority should consider the prior knowledge, personal experience, and culture of the receiving stakeholders. Such characteristics can improve the warnings and allow them to be tailored to the receiving group, e.g. if the population affected has experienced a similar hazard previously. *Innovations improving the visualization of risk and uncertainty for impact*-based forecasting • *Global Multi-Hazard Alert System (GMAS):* at the global level, is one promising initiative to improve availability and accessibility of EWS

	especially focused on high-impact weather events that represent trans-boundary risks. GMAS will be built on the alert hub technology to enable timely aggregation of relevant authoritative warnings and alerts related to high-impact weather, water, ocean and climate events towards an Earth Systems approach. GMAS will also leverage WIS to maintain a repository of authorized warnings, alerts and related information.

2. Complementary MHEWS issue briefs

2.1. Co-design
2.2. Common Alerting protocols
2.3. Evaluation of the benefits of EWS
2.4. The final mile
2.5. Governance frameworks for MHEWS

Co-design: tailoring warning and advisories to specific user needs

Research shows that tailoring warnings to the needs of recipients increases their effectiveness. However, this benefit, in better warning response, has to be set against the cost, complexity and potential for inconsistency of doing so. The benefit is not restricted to economics, but may include a variety of non-economic benefits and ethical issues of human rights as well. Here we explore aspects of tailoring and the benefits of doing so, with a view to providing some guidance on how the optimum level of tailoring might be identified.

1. Tailoring the underlying prediction.
   When working with a decision maker to improve their access to predictions of hazards, the basis for selecting the source of that information will include several factors, of which accuracy or skill is likely to be an important one. On the other hand, a provider of information, trying to optimize the value to users of the information they provide, has to choose which improvements to their prediction system to implement. In both cases it may appear to be beneficial to focus the evaluation on the conditions of interest to the user, i.e. the hazard itself or perhaps the extreme weather conditions that give rise to the hazard – both things that occur rarely. If the exercise is being undertaken following a disaster, it may even be felt that the most important consideration should be that the disaster would have been predicted with the new system or data source. This approach can be very dangerous, typically leading to over-prediction and loss of confidence in the warning system. While there are unbiased methods of assessing extreme values of weather variables and of assessing the skill in predicting

occurrence of an event, in both cases they are not immediately intuitive and so are not the most widely used evaluation approaches. In addition, the small number of data points available for extreme events means that the error bars in the score are likely to be very broad. Even if different information sources are reliably identified as giving the best guidance for different phenomena, the risk of inconsistent predictions is considerable. So, for instance, if one information source gives better hurricane track predictions and another gives better hurricane intensities, it would be foolish to rely on the track from one and the intensity from the other. For developers, the traditional response to this problem has been to focus on the middle of the distribution and hope that the extremes will get better if the median does. While this has some merit, as it ensures consistency and engenders trust, it is no longer sufficient. The combination of very high resolution models, ensemble weather prediction, ubiquitous data gathering, reanalysis/reforecasting of the past and new statistical measures, means that reliable, unbiased evaluation of the whole probability distribution is becoming possible and should be adopted to the greatest extent possible. In short, by combining multiple information sources, each expressed as an unbiased probability distribution, based on evaluation against re-analyses, it should be possible to produce results that are consistent and that optimize the value to the decision maker. It is recommended that prediction systems should not be optimized for prediction of particular hazards, but that ensemble predictions should be used that have been calibrated to give reliable results for all parameter ranges over long periods.

2. Tailoring the prediction products.
   Having obtained a source of predictions that is reliable, accurate and skillful, there are many ways in which information may be extracted that is tailored towards specific users. For instance, in aviation warnings, specific thresholds of visibility and/or cloud base/ceiling have been identified as being important for certain classes of aircraft and/or airport. Extracting the probability of these thresholds being passed means that an operator can focus immediately on their specific concerns, rather than having to identify their locations of interest and thresholds of interest on multiple maps. If they wish to, they can also inform the service provider of the probability threshold at which they wish to take action, enabling an even more tailored service to be provided. At this point, some potential pitfalls emerge, as one operator may receive a warning to take action at a different probability level to another, resulting in apparently similar but conflicting warnings. If shared without adequate explanation such differences can cause confusion and loss of trust. Other means of tailoring include recalibration, bias correction and derivation of user-relevant variables (both physical and socio-economic). Thus a flood forecast may be presented as a flood level above the river bed, or as a map of flood depth, or more specifically in terms of the depth on roads to the Highways Department, the probability of entering houses to the public, or the probability of shutting down an electricity substation to power company. In the pressured environment of an emergency response team, the more precise and actionable statements are likely to produce more effective responses with less room for error. It is recommended that warnings of the highest identified risks should use tailored prediction products incorporating the probability of specific hazard thresholds being crossed, and information about exposure and vulnerability of communities in the threatened areas.

3. Tailoring the communication.
   This area offers the greatest opportunity for tailoring with the minimum risk of confusion. Some obvious examples are warning dissemination in multiple languages, according to the make-up of the population, or through different media (Newspaper, TV, radio, internet, mobile app, social media, …) according to accessibility by the population. Use of geographical names that are locally understood is crucial. For instance labelling a flood warning by the name of the river reach will not be helpful to city dwellers who do not realise that a river exists, let alone that they could be flooded by it. Maps can be

powerful tools for communicating the proximity of a warning area to dispersed communities – but only if they are familiar with maps and competent at reading them. Colours can provide powerful support to communication - the green-amber-red sequence of traffic lights is understood in many cultures, but not all. The use of cartoon characters to communicate has been very successful in some cultures, but not all. Since users will often seek confirmation from friends and family before responding, it is important that different means of communicating the information are consistent and reinforce each other. It is recommended that design of warning communication systems should always start with a survey of the targeted recipients to determine how and in what forms they would expect to receive warning information.

4. Tailoring for specialists.
   Where there is an emergency manager for a large infrastructure facility that will affect thousands of people, the case for tailoring very specifically to that person's needs is very strong. It is imperative that the response is pre-planned and that it is carried out quickly and effectively when the warning threshold is reached. This may be assisted by simplifying communication down to a code, which is learnt and practiced by each provider and user. The same holds for organisers of large public event such as pop festivals. Tailoring for major public facilities such as schools or hospitals is more complex, but equally important. Candidate specialist users for tailored warnings include: power generators and suppliers, water supply, dam operators, telecommunications, road transport, rail transport, air transport, marine transport, food retailing, education, emergency response, health services, waste disposal, public event organisers, major employers and businesses. It is recommended that such users should not be using generic public warnings to take decisions. They should have carried out a risk assessment for their business, which identifies the hazards they are exposed to and the level of risk for each. They should also have a risk response plan which details the trigger points at which action must be taken, together with the information needed, both to identify the trigger and to inform the action. The receipt of a tailored warning should be the primary trigger for preparatory actions ahead of weather-related hazards.

5. Geographical tailoring.
   When considering tailoring of the information behind a warning, making allowance for geography is perhaps the most obvious and most necessary. It is especially evident when forecasting wintry weather in complex terrain, when low-lying valleys may have rain while higher up the slopes snow is accumulating. This may be communicated by referring to the height of the snow line, but only if there is evidence that citizens know what height they are at. Such tailoring of warnings is especially important for tropical cyclones, where the main hazard may be wind over the sea, the resulting storm surge along the coast, and heavy rain over inland hills or mountains, leading to flooding in downstream river catchments. Proximity to rivers is a key driver of risk from flooding, but while most people will know the names of the main rivers in their region, few will know the detailed nomenclature of reach, tributary and catchment used by local hydrologists. Warnings that refer to settlements at risk or escape routes that are safe or threatened may use names that are only current in the immediate vicinity, so that visitors are unaware of their meaning. For instance, reference to numbered highways or to numbered junctions on a highway will be incomprehensible to a significant proportion of the travelling public. Maps can be a powerful way of avoiding these difficulties, provided the maps are clearly located relative to major towns, coastlines, major rivers or other widely known features. It is recommended that high risk areas arising from geographically constrained hazards should be identified and that suitable tools for communicating the geographical constraints should then be developed in collaboration with local people so as to increase warning skill and build trust.

6. Other areas for tailoring.
   Research has looked at many other aspects of warning design that can affect how particular groups receive, interpret and respond to the information. Cultural cues can be very important, e.g. the color red has particular and conflicting cultural meanings. Similarly, the idioms used in the language can be as important as the words. Phrases such as “snowing handkerchiefs” or “raining cats and dogs” may strike a chord in the native population, but be misunderstood by incomers, even those who are long term residents. Gender is of particular importance given that women are often more exposed to hazards than men due to their occupation. However, when considering tailoring for gender it is necessary to consider the route by which the warning will reach women. A direct route, e.g. by social media, will require different tailoring from an indirect one, e.g. through a village chief or street warden. Another potential area of tailoring comes from the psychological response of recipients to any new situation. Some people typically respond positively, seeking to turn it to their advantage, while others are followers of the crowd, and yet others will fight against change. In the West, marketing companies have learnt to target these groups differently, and it is likely that similarly targeted warning messages may be effective, though research has yet to demonstrate this. It is recommended that decisions to tailor along these lines should be guided by careful analysis of the primary risks that need to be reduced, of who is at risk, and hence of the cost-effectiveness of any tailoring.

7. Co-design in generic warnings.
   It will rarely be the case that a high degree of tailoring can be economically justified for public warnings. An alternative is to use co-design to design a compromise generic warning system that meets most needs and to use education to embed its characteristics in the users’ cultures. Considerable experience has been gained in this process and it is clear that co-design activities must be very carefully planned to ensure an adequate voice for all sections of the community. Evidence also suggests that a feedback loop is required in which community representatives first identify what they feel are the problems with current capability and then criticize successive sets of upgrade options in an iterative fashion. Not only does this help to produce effective warnings, but it also builds a sense of ownership in the community that helps with the adoption and use of the final product.

8. Measuring the effectiveness of tailoring.
   A step that is often forgotten when implementing new or upgraded warning systems is to evaluate the benefit. While it would be desirable to demonstrate benefit by comparing metrics of death, distress and damage from disasters before and after the change, it is rarely possible to do this. Since the objective of tailoring is to help the recipient to make a better decision, surveys of people’s reactions to warnings are probably the best available tool. A baseline is required in order to measure improvement, so surveys should be established before any change is made and, ideally, the format should not change. If surveys have been made as part of the co-design process, e.g. asking people how they would respond to different styles of warning, it may be appropriate to continue these. However, the difference between the anticipated response and the actual response may be significant, so post-event surveys, in which people report what they received and what they did, are to be preferred.

Despite today's amazing telecommunications services, there are still too many people in harm's way who do not get timely alerts so they can protect lives and livelihoods. This gap in effective alerting is especially acute in least-developed and developing countries, which are often the most vulnerable as well. Yet, one reason for the gap could be easily addressed: help those countries implement the same transformative approach already delivering greatly enhanced public alerting in the rest of the world.

Specifically, organizations interested in disaster reduction could help all countries fully leverage the Common Alerting Protocol (CAP) standard to communicate the key facts and the recommended actions for any emergency. Use of CAP greatly increases warning efficiency and effectiveness, primarily because a CAP message carries data intended for machine processing as well as information targeted to humans.

Leveraging the CAP standard should strive to involve all the willing actors in emergency management. This includes the commercial sector as well as governmental and non-governmental sectors. These various actors have many complementary and sometimes overlapping roles, ranging from alert origination through dissemination to adaptive emergency response using dynamic feedback.

The following seven issues highlight where a focus on CAP-enabled alerting would have major impacts.

1. New Media is Replacing Mass Media.
   Much of today's public alerting infrastructure assumes that mass media, such as broadcast radio and television, is the best way to disseminate alerts to a large percentage of people in harm's way. But, as people increasingly substitute online media for broadcast radio and television, those people do not get emergency alerts sent as broadcast radio interrupts or television "crawl text". This issue must be addressed by various online media. Google has pioneered in leveraging CAP to get emergency alerts to people online using Google tools. Also, digital highway signs and billboards carry CAP alerts in some places, and amazing opportunities are emerging to automatically create or disseminate CAP alerts using "Internet of Things" technologies and "Smarter Cities" innovations.

2. Some Nations and Hazard Types are Missing Out.

   Today, 75 per cent of the world's people live in nations that already have, or are currently developing, official news feeds with public CAP alerts at national-scale. However, as noted above, uptake of CAP-based alerting has lagged in developing countries even though they are often among the most vulnerable. Also, CAP uptake has been far stronger for weather than for other hazard types, and CAP remains unknown to most disaster management offices worldwide. The World Meteorological Organization (WMO), the International Telecommunication Union (ITU), the International Federation of Red Cross and Red Crescent Societies (IFRC), and the Climate Risk and Early Warning Systems (CREWS) initiative have been supporting CAP outreach for years, but other international bodies such as the UN-led Emergency Telecommunications Cluster (ETC) could play an outreach role as well. The issue that some nations and hazard types are missing out on CAP can be addressed with concerted international efforts at basic outreach, and by increased support for the sharing of good practices, techniques, and technologies associated with CAP-enabled alerting.

3. People with Special Needs or a Language Barrier are Under-served.
   Many people in harm's way are underserved with current public alerting because they are blind,

deaf, cognitively impaired, or they do not understand the language being used in the alerts. These issues can be addressed by exploiting the data features of CAP and with automated translation.

4. Alerting Areas Should be Precise.
   Trust in an alerting system is eroded when people get alerts not intended for them. This happens often in systems based on mass media broadcasting, but alerting coverage can be much more precise with various other means of alert dissemination. This issue is addressed with CAP alerts that include a precise area delineated by polygons or circles in addition to the textual area description.

5. Issuing Alerts Should be Quick and Easy.
   Alerting authorities that have yet to implement CAP must contend with many separate methods for sending out alerts. Typically, this includes making phone calls, sending Faxes, sending e-mails, posting to a Web page, and posting to Facebook and Twitter, among others. This activity consumes valuable time and distracts from the mission of composing accurate and actionable alerts. With CAP, this issue is addressed in that a single CAP message disseminates over multiple alerting methods.

6. Situational Awareness can be Better Shared.
   In managing any emergency situation, it is essential to assimilate relevant information of many types and from many different sources, at scales ranging from local to city-wide, provincial, national, regional, international, and global. This is called "Shared Situational Awareness" or maintaining a "Common Operating Picture". That key information includes real-time alerts, but such alerts are difficult to ingest, use, and share if they are communicated in a broad range of media and formats. This issue can be addressed by having alerts available in CAP format as much as possible.

7. Sudden-onset Events Require Immediate Alerting.
   Some types of hazard occur so suddenly that seconds can mean the difference between timely, life-saving alerts and alerts that arrive too late. Example hazards include earthquakes, tornadoes, tsunami, flash floods, volcanic eruptions, landslides, avalanches, and active shooters, among others. This issue can be addressed by sending CAP alerts immediately to an online facility such as an Alert Hub which immediately disseminates those alerts by all available media. (In the case of mobile phone alerting, "cell broadcast" is immediate whereas SMS is often too slow.) Here it is noted that the digital aspect of CAP messages enables immediate action not only by people but by devices such as sirens, highway signs, train controls, and other automated mechanisms that help save lives.

Evaluation of the benefits of EWS

Investment in an early warning system requires an understanding of the value of the benefits that will follow – the avoided deaths, damage, property losses, relief cost, distress, disruption and system failures. Each of these impacts can be assessed in monetary terms: e.g. by using a notional "value of a life" for deaths, the value of lost DALYS (Disability Adjusted Life Years) or QALYS (Quality Adjusted Life Years) for disability or illness, and the value of lost services or production for disruption. Note, however, that one person's loss may be another's gain, or a loss may be temporary and be recovered at a later date. It is necessary to be careful, therefore with business losses, when data are aggregated to estimate value to the nation, as opposed to the individual. There is a further benefit to society beyond this as the existence of a MHEWS provides security both to individuals and to business. For individuals and society, the resulting peace and security of mind has a direct value in social resilience (well-being) that may be perceived by the person and society. For business, the security of knowing that a MHEWS exists, may be manifest in lower charges for capital investment, reduced insurance costs, lower contingencies and hence increased economic activity and higher profitability. The value of a warning system comes from the effective working together of all of its parts. To achieve and maintain this requires routine evaluation of all components of the value chain A comprehensive review of this subject is given in "Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services" (WMO No.1153, 2015).

9. Types of losses from natural hazards

   The losses caused by natural hazards can be divided into direct or indirect social, economic and environmental costs. Direct losses, such as damage to buildings, are relatively easy to attribute to a particular hazard, whereas for indirect costs, such as illness or business failure, it may be much more difficult to determine how much of the loss is attributable to the hazard.

   Social losses include death, injury, illness, stress and mental illness. There are also indirect economic costs associated with these losses including cost of care and loss of productivity.

   Economic costs include damage to buildings, infrastructure, agriculture etc and loss of business, tourism etc. For buildings, the loss is the cost of repair or clearance and reconstruction. For infrastructure, the loss of service is likely to be greater, whether it is carried by the operator or by the customer. Agricultural losses can be in the land itself, e.g. due to erosion or inundation, or through damage or delay to crops and/or animal stock (e.g. in a drought). Business losses are generally indirect and may follow from loss of manufacturing capacity, or inability to deliver, or loss of sales opportunities. Tourism is affected both by the actual loss of infrastructure, buildings etc and by the loss of business due to perceptions that a location is not safe.

   Environmental costs can arise due to erosion, vegetation loss, streambed and seabed damage etc which can indirectly lead to loss of biodiversity and higher pollution loadings as well as damage to landscape value.

10. Measuring losses from natural hazards

    The most reliable measures of socio-economic losses from hazards are obtained from insurance records. These enable both the nature of the loss and the hazard that caused it to be identified and for aggregate statistics to be generated. Unfortunately, even in developed countries, many losses are not covered by insurance.

    Social losses can largely be estimated from primary care and hospital records where these are kept. Deaths and cause of death are available in most countries and are a required measure for the Sendai Framework. As well as medical records, local media often record deaths in a disaster. Injuries are unreported in many countries, unless a certificate is required for time off work. Illness can be difficult to associate with the hazard, e.g. vector borne diseases associated with a flood or exacerbation of existing conditions by cold or heat, and may also not be recorded. The heavy toll of post-disaster mental illness has only recently become recognized, and is particularly difficult to identify in existing records, despite clear evidence of its impact on productivity of affected workers.

    Property, business and agricultural losses may be obtainable from insurance records. For uninsured losses, a modelling approach may be the best approach, using the footprint of the hazard and calibrating against insured losses in a comparable area. Government owned organisations are often tacitly insured by government. In such circumstances records of cost are often absent and, again, modelling may be the only way forward. Agricultural losses can be particularly difficult to estimate, as they depend as much on the way the land is being used, as on the hazard. For instance losses from flooding of a river flood plain might be considered to be due to agricultural practice rather than the flood hazard, but the availability of a warning system might allow for productive use of that land during drier periods.

Costs from the loss of infrastructure are difficult to obtain unless there is a policy of recompense to customers. Even then, the loss is likely to be the charge that would have been made for the service during that time, rather than the true loss to the customer, which may be greatly magnified by the sudden and unexpected cessation of the service. Where recompense is not offered, reports of periods of outage in the media may be the only source of information on which to case estimated losses.

Environmental losses are almost impossible to estimate, partly because the value of ecosystem services is not yet agreed, and partly because impacts that are negative at the time may turn out to be positive after a recovery period. Assessment is further complicated by the impact that human recovery operations may have on the natural recovery processes. Where there is specific damage that has to be repaired, e.g. to replant a forest, the cost of this can be estimated from

11. Reducing losses with MHEWS

Early warnings enable early action to reduce losses, e.g. by:

Reducing the hazard. This is particularly relevant to fluvial flooding, where careful water management can prevent flooding of vulnerable property. Large rivers that have been dammed for water storage and power generation can be managed to reduce water level ahead of a flood given sufficient lead time, thus reducing the risks associated with unplanned releases.

Reducing exposure. Evacuation is the classic response for protection of life from hurricanes, storm surges and wildfires. It removes people from the danger zone and thus reduces the loss of life. Exposure may also be reduced by implementing temporary protective measures such as flood barriers and fire breaks.

Reducing vulnerability: travel. People are most vulnerable when they are travelling, so reducing travel during severe weather can save life and reduce vehicle damage. There are many weather hazards that are associated with increased risk to transport, including strong winds, snow & ice, fog.

Reducing vulnerability: medical. Many people rely on power for medical aids and on regular supplies of medications or frequent treatment, any of which may be interrupted by a disaster. A MHEWS can provide information to enable vulnerability to be reduced, either by moving the person, by providing backup medication, or by installing a temporary power source.

Enabling early recovery: power. Loss of power networks is a common impact of natural hazards. MHEWS can enable pre-positioning of resources to enable an early start to recovery work. MHEWS can also provide information on the time at which it will be safe to start recovery.

Enabling early recovery: rest centres. People evacuated during the response phase of a disaster will be collected in rest centres. MHEWS can provide the preparation time for such centres to be opened and resourced in an orderly manner, and for arrangements to be made for restocking with food, water etc as soon as the hazard has passed.

Enabling early recovery: backup services. People who are able to remain in their homes during a disaster need access to basic essentials of food, water, power and communication. If these are not available they may be forced to evacuate, increasing the cost and disruption to the community. MHEWS can provide the information to enable temporary backup services, such as mobile food canteens, water tankers, mobile generators etc. to be prepared and pre-positioned ready for deployment as soon as it is safe to do so.

12. Hidden benefits of MHEWS

    The process of setting up a MHEWS involves engaging with a community to explore the risks that they face and how they might respond to them to reduce the consequences. This process, in itself, raises awareness and can lead to reduced vulnerability.

    The existence of early warnings, along with other risk reduction measures, can lead, at the corporate level, to reduced financial costs – for borrowing, investment, insurance – enabling easier and faster development to occur. At the personal level it can provide an enhanced level of safety and security encouraging skilled people to move to, or stay in the area. Such measures may also reduce social vulnerability (e.g from disease outbreaks such as malaria) during migration. When a hazard occurs, a warned population has been found to suffer less stress than an unwarned one, not only reducing post-event mental illness and cost of treatment, but also enabling an early return to productive employment.

13. Measuring perceived benefit

    Instead of attempting to measure benefit in a bottom-up way, we can use social science methods to estimate the value that users place on the warnings. This may be done by surveys offering a choice of subscription amounts, or by comparison with other public goods, etc. Similar approaches can be used with business users – though the information may already be available in the marketplace if commercial weather information providers are operating. Such estimates may be smaller than the bottom-up calculation, if end users are unable to pay the calculated cost, or they may be larger, if users are given a feeling of safety that contributes to their well-being, beyond the cost of any specific losses. Care must be taken to ensure representative sample surveys for such calculations, and caution should be exercised when sample results are scaled up to the full population to test the credibility of the result.

14. Modelling avoided losses

    The goals of MHEWS evaluation are to estimate the reduction in loss from that which would have happened without a warning and to estimate what the reduction would be from a new warning system.

    For insurable losses, catastrophe modelling has been developed to generate estimates of the cost of a disaster. The average cost of recovery for each insured property/business, and the distribution of damage within the footprint of a storm or flood, are estimated from insurance records. Given a predicted or observed storm, the expected recovery cost can then be estimated from its footprint and intensity. The full cost can then be obtained by adding an allowance for uninsured losses and omitting losses that are simply transferred within the economy (e.g. a lost contract due to a storm is not an economic loss to the country if another contractor took the job).

    For social losses and indirect losses, epidemiological approaches are more appropriate. These assess the likelihood of a statistical association between the hazard and the impact, using comparable sets of data with and without the hazard. Care must be taken to exclude the influence of other differences between the sets of data that might introduce a spurious correlation, such as different season, day of the week, geographical location, etc.

Studies of the responses to warnings have identified a range of factors that inhibit reducing the cost of a disaster to zero. These include the absence of any effective action to take, failure to act on a warning, and failure of the warning to reach those who could take action. Some of these factors can be estimated by social science methods, such as focus groups or surveys. Others may be estimated by calibrating against the recorded loss, or by assuming the same values as found elsewhere. Research in hazard impacts will help to inform better models of avoided losses.

15. Modeling benefits to attribute value and justify investment
The ability to model the benefit of a warning system enables continued operation, improvement and replacement to be justified using cost-benefit analysis. This requires not only modelling of the avoided losses, but also assessment of the costs of running the warning system and of responding to the warnings (including false alarms).

    A warning system typically consists of many actors in different organisations (e.g. a flood warning may involve rainfall observation, weather prediction, river flow prediction, inundation mapping, warning formulation and warning communication), each of which typically needs to justify its investment separately. A well-constructed and calibrated model of the value chain can help in attributing value to different actors and hence to a more effective analysis of costs and benefits.

16. Examples
The Red Cross has demonstrated cost-effectiveness of taking early action in developing countries based on forecast exceedance of impacts-related thresholds. Effectively, they require the probability of exceedance of the threshold to exceed a level determined by the ratio of the cost of early action to the cost of responding after the disaster has happened. Evidence from pilot projects has demonstrated that forecasts are good enough to meet this criterion in many cases.

    The HPC procurement by the UK Met Office in 2015 was based on a business case that included an evaluation of the benefits of flood forecasts derived from rainfall and coastal surge predictions. The evaluation used a model of the fraction of avoidable damage that was actually avoided, taking account of the proportions of people receiving the warning, understanding it, believing it, being able to take action, and choosing to take action. Estimates of these proportions were obtained largely from sample surveys. The aggregated figures were calibrated to agree with insurance statistics (adjusted for non-insured fraction). Although subject to uncertainty the resulting figures are sufficiently stable to provide useful support to investment decisions.

The Final Mile: Communicating action information; Trust and the Authoritative Voice

The key to the value of warnings is the action that is taken by the recipient. If the warning does not change actions it is of little value, though if it merely makes the recipient more psychologically prepared, that may both help them to respond to whatever happens and to be less distressed in the aftermath. The popularity of the newspaper headline “Why weren’t we warned?” suggests that simply knowing something is coming has psychological value even if there is no response available or needed. Many factors contribute to determining how a warning is responded to, some associated with how it is communicated, but just as important is how it is received. We explore the main ones here, touching on the need for the warning to connect with the decision that has to be taken, on the choice of different media, on language and design, on establishing trust in the source, and on ensuring that the recipient knows what to do and finally on the challenge of evaluating success. Recent research in these areas from the WMO High Impact Weather (HIWeather) project was highlighted in a collection of papers in the International Journal of Disaster Risk Reduction special issue, "**Communicating high impact weather: Improving warnings and decision making processes"** published in September 2018.

8. Making a connection.

   Protective action is taken at the end of the warning chain when the event happens, so design of a warning system must start there. Once the risks to a community are known, the first step in the process of designing a warning system is to identify potential protective actions, including those to be taken in the event of a previously unidentified threat. Those actions will only be taken if and when appropriate information is received and understood by decision makers, including the public. In particular, the move towards early action based on forecasts of impact, requires communication of key trigger points being reached.

   However, there is also a constraint at the other end of the warning process. Some information is impossible to provide. To take an extreme example, if a decision to empty a reservoir ahead of a flood required a 90% confident forecast of extreme daily rainfall a month ahead, the chaotic nature of the atmosphere tells us that it cannot be done. So an iterative process is required, between what is wanted by the decision maker and what is possible given available science and resources. There are, of course, many decision makers, each with different decisions to be taken. Ensuring that each person has the information they need to make their decision, that it reaches them and that they understand and trust it when it arrives, is complex and trade-offs will need to be made for the process to remain manageable.

9. Reaching the user.

   The most fundamental barrier to warning response is if the information simply doesn't reach decision makers. This may be because they are in remote locations without communication links, that the communication chain was broken due to inadequate operating procedures, that the warning medium is not used by the intended recipient or that the recipient was not receiving that form of communication at that time, e.g. due to being asleep at night. The migration from newspaper to radio to television to internet to social media as primary information sources has meant that issuers of warnings must continually be extending the channels they use in order to reach their audiences. Alerting authorities in countries worldwide are now using the Common Alerting Protocol (CAP) to leverage all available media as they issue alerts for all manner of emergencies. However, it is not necessary to reach everyone with media alone--"word of mouth" can be very effective as well. For instance, a network of street wardens or volunteers on bicycles can relay alerts even where media are scarce. Monitoring of the number of people receiving warnings is important both in advance, using surveys to plan the use of communication channels for optimal coverage, and in real time, using electronic messaging tools to identify where a lack of receipt of warnings may leave groups such as in a vulnerable state. Such studies need to pay particular attention to groups that may not receive media communications due to gender, age etc.

10. Understanding the information.

Ensuring that the recipient understands the information provided and can relate it to their need is perhaps the most difficult challenge in communicating a warning. It is as much about perceptions as about facts. There are some obvious hurdles to jump, such as using language that is understood by the recipient. This may mean using a local language rather than a national one, but it may also mean using common language rather than professional jargon. Language is more than words, so the mode of expression must be consistent with the message or the recipient will be confused. Use of a word that is commonly used as a "joke" word may undermine a serious message! For these reasons, some warning systems use symbols, emoji, cartoons or video to convey warning information. However, these can also be misunderstood. The safest solution seems to be to use multiple representations of the same information that will reinforce each other and achieve the widest impact. When graphical components are being used in warnings, especially maps, it is essential that they are well designed and that ambiguity is reduced to a minimum. Not everyone in a warning area is going to recognize the shape of a county boundary, for instance, though most will know which road will take them to the nearest city. Achieving successful warning communication is complex. It needs to be tested and to evolve iteratively in the light of feedback from users. Complementary to the design of the warnings is a need to ensure the recipients are familiar with it, through periodic education and, if the consequences are serious enough, through practice drills.

11. Believing the information.
    Belief of information and trust in its source are intimately connected and both have a strong influence on how people react to a warning. All sorts of prior experiences can have an effect on this. For instance, if the source has established a connection with the indigenous knowledge of a community, they are more likely to be believed. If the warning is delivered by someone who the recipient is used to seeing in a place of authority, they are more likely to be believed. Of course, this presupposes that the recipient knows where the information has come from. These are issues that are familiar to those involved in marketing a brand. They know that it must be kept in the public eye, that it must be associated with good outcomes for their target audience, and that it must not be tainted. The issues at stake for a warning agency are different, but the challenges are the same and the understanding of psychology needed to get it right is also the same. The World Meteorological Organisation promotes the concept of National Weather Services providing an "authoritative voice" for the weather-related warnings in their countries. Such a voice can be a very effective means of reducing the impact of hazards, provided it satisfies the marketers' criteria. However, recipients of warning information also have their own cultural or personal knowledge that may help or hinder their acceptance of the warning. Evidence from tornado disasters in the USA has shown that many people fail to take shelter because they wrongly believe, based on previous experience, that there is something preventing tornadoes from affecting their area. In a more primitive society, such opinions may be couched in supernatural terms. Unless these assumptions are acknowledged at some point, warnings are likely to continue to be ignored. It is often said that false alarms reduce trust in warnings, but research findings show that inconsistency is a much greater barrier to action, and that the effect of false alarms can be removed by post-event explanation – especially when nearby areas were affected. Previous exposure to a hazard is usually a help to response. In areas with transient populations few people live in the same place long enough to form personal memories, so alternative forms of memory, such as flood marks and anniversary commemorations, can be particularly important.

12. Translating information into action.
    Several research projects have identified that the biggest gap in ability to respond to a warning is the failure to identify a feasible response. For professional recipients, the actions to be taken should be clear, recorded and rehearsed, as in forecast-based early action. However, for the public that is much less likely to be the case. A personal risk response plan is the ideal and education is needed to persuade people to develop one and to set aside the resources that they will need. Education is most likely to be effective and remembered shortly before and during a hazard event. There is a role for "very early warnings" here. Where weather hazards are strongly seasonal, it may be at the same time each year. Otherwise, a month ahead forecast would give sufficient time for a pre-prepared education campaign to be screened on a variety of media. The warning itself could then contain trigger words that link to the promotional material, reassuring recipients that they know what to do. Recent research has highlighted that recipients of warnings containing potential responses express an increased willingness to take appropriate protective actions. However, it must be recognized that a proportion of recipients may have constraints on their ability to carry out recommended responses. It is necessary that the education material should take account of this, perhaps advising them to seek help from neighbours, or providing a helpline to request additional help when the warning is issued.

13. Measurement.
    Whether warnings are provided by government or by commercial business, it is important to know how effective they are so as to justify their introduction, continuation and improvement. The benefits of warnings are primarily in reduced deaths, distress and damage. Distress is a complex area that encompasses physical injury, shock/mental illness and loss of employment. While it is possible to use hospital data for deaths and perhaps for some aspects of distress, and to use insurance data for some aspects of damage, these will always be the residual after the warnings were issued. So we need a means of estimating what those numbers would have been without the warning. But that is the same problem that we use impact prediction models to address when formulating the warning. So we need to take the best, unbiased impact models and apply them to the observed hazard, so as to estimate what the impact would have been. Such models can also be used to provide a baseline to estimate change when warnings are improved. There are very few examples of this being done at present. In England, the Environment Agency routinely estimates the saving in property damage due to flood defences, using a model of damage related to the depth of flood that would have occurred without the defences. Such an approach, together with routine post-event surveying of how people responded, would provide the information needed both to assess current performance and to justify future investment.

Governance frameworks for MHEWS

A Multi-Hazard Early Warning System forms part of a comprehensive risk reduction strategy for an administrative authority – typically a city, state or nation. Its governance must therefore take place within an overarching risk reduction framework consisting of policies for risk assessment, risk prevention, reduction and management, hazard detection monitoring and forecasting, disaster preparedness and response planning, and disaster recovery. In this regard, political support is vital for the success and sustainability of MHEWS.

Governance of the MHEWS

17. Scope

    The governance structure should make clear the scope of a MHEWS within the broader disaster risk reduction framework. Specifically, it should specify the audiences to be served: e.g. government emergency response, the military, businesses, the public, critical facilities/utilities operators, farmers/agriculture. It should specify the role of the warning service (if any) in each of the phases of a disaster: education, exercises and preparedness; early action to mitigate the hazard and protect livelihoods; early response to minimize damage, death & disruption; and early transition to recovery. It should specify lead times and level of detail expected, and how forecast uncertainty should be dealt with; make clear whether a 24-hour 365 days per year service is needed (probably yes for windstorms, but no for drought). The governance schemas should specify the communication flows and decision-making chains.

18. Monitoring

    Monitoring is fundamental to all warning systems: to monitor the hazard precursors, the hazard itself, and the exposure/vulnerability of the population. The precursors are the input to the forecasts that underpin the warning. The actual hazard must be monitored to enable verification of the accuracy of the warning and to accumulate statistics of occurrence. Exposure and vulnerability are combined with the hazard to estimate risk. As warning systems become more impact oriented, monitoring increasingly needs to capture the impacts of the hazard, so as to support warning verification, enable enhanced vulnerability assessment and to build expertise. Spatial and temporal resolution of monitoring should take account of the scales of variability of the hazard and of the affected population.

    Monitoring may be carried out by different agencies, both public and private, for different purposes using different data collection methods, but they must be current, quality controlled and integrated consistently. In order to do this, the description of the data (the metadata) must be clear and complete. Data should be mandated for disaster reduction purposes, so that they are shared without impediment to all agencies involved in the warning chain, and so that the needs of disaster reduction are taken into account in data gathering. Hazard monitoring for infrastructure safety is normally the responsibility of the infrastructure operator. If requirements are simple, the operator may be able to use public monitoring information. More complex information requirements should normally be funded by the operator, access to the data may be mandated to support disaster reduction, and funding support may be appropriate in this case.

    Interpretation of monitored data requires specialist skills and so may need to be carried out by experts. The results of such interpretation should be made available in a timely manner to other agencies in the warning chain, taking account of the need to combine hazard with exposure and vulnerability at scales that enable effective response.

    For strategic users, such as central government, it is valuable to have a regular assessment of the risk status across relevant hazards in a consistent and compact presentation, such as that used in the UK Daily Hazard Assessment. There, the national-scale risk from each natural hazard that affects the UK is classified in a colour sequence of ascending risk (green – yellow – amber – red), accompanied by a commentary. For some hazards this is based solely on monitoring data, while for others it also includes a forecast.

19. Preparation of warnings
    A warning is created through the contributions of many people, who may reside in different offices, organisations, cities or countries. Successful warning systems have very clear and open procedures for what each partner will contribute, including timescale, format etc.. They build a personal relationship among the staff who will be involved, so that they learn each others' technical languages, and participate in joint training and exercises. To build trust, there should be open sharing of data, products and procedures. Each partner should be aware of the key parameters that concern the decision maker(s) who is to use the warning – including vulnerable locations and threshold values of key variables, both of which may change according to circumstances. A clear definition of how success will be measured should be provided as this will strongly influence the behavior of those issuing warnings, e.g. in terms of number of false alarms or misses. These requirements apply equally whether the partners are government, private or third sector organisations.

20. Delivery of warnings
    The science of how to deliver effective warnings is developing rapidly and is summarized in the issue brief on "the last mile".

    The need to reach as many people as possible with a warning message that they can understand requires that delivery is through multiple channels using different media and tailored to the audience. Since delivery will likely be through independent media companies, it is essential that the warning message remains consistent. The delivery route and formats should be as common as possible across different hazards, especially for hazards that may occur together. However, to maximize trust, the source of the information should be clearly linked to people or organisations that are trusted for each hazard. Warnings should be linked to public education, preparedness and impact mitigation programs, including insurance, and where available, to pre-prepared response plans, especially when exercises have been held.

The Broader Governance of Risk

21. Policy & Legal framework
    It is a primary duty of governments to protect citizens from hazards. There should be a clear legal framework and policy covering safety, security, human and natural hazards, which identifies authority and responsibility for the key aspects of risk management: identification, preparation, response and recovery (e.g. in many countries the authority during the response phase will be the police or army and it will be everyone's responsibility to do what they say). Where there is multi-layered government, policy should also set out criteria for escalation, e.g. from city to state to country. Since hazards can cascade, potentially into other greater hazards (e.g. when a natural hazard destroys infrastructure) identifying how coordination will take place is key, especially where one part of the response is owned by a private business, but with potential impacts on the public. Where responsibilities have been identified, there need to be standards, together with inspections to ensure compliance, and penalties for failure.

22. Risk identification and assessment
    A disaster risk management policy must be underpinned by analysis of the risk posed by different hazards and by combinations and cascades of hazards. This requires mapping of the hazard, of exposure to the hazard and of vulnerability. Responses to hazards may be to protect or to warn.

Since protection is generally expensive, and may not be feasible for extreme cases, analysis of the annual probability of each hazard is often combined with the estimated damage costs to decide on a level of protection. However, government also needs a plan for what happens when protection capacity is overwhelmed. In this case, analysis of the “reasonable worst case scenario” can be helpful.

Neither hazard assessment and maps nor exposure and vulnerability maps are fixed in time. They need updating as new information becomes available, as the climate changes, as cities expand, and as the vulnerability of their residents changes. A cycle of routine updating of these maps needs to be specified, perhaps linked to the census or land use planning cycle. Any updated information should be immediately made available to MHEWS to ensure that risk estimates are up to date.

23. Disaster Risk management responsibilities
A primary role of disaster risk governance is to define responsibilities for risk assessment, risk prevention and reduction, and disaster response. The government will have responsibility at the highest level in policy and planning, including the setting of standards for buildings, land use and infrastructure. Building codes, land-use policy, and infrastructure investments must be risk-informed to reduce vulnerability and improve resilience in the long term. More generally, it should be the responsibility of every person to be aware of the risks to which they are exposed, and to act to minimize them and any risk that they may pose to other members of the community. Owners of businesses have a particular responsibility to ensure that their operations and staff are, as far as possible, protected from hazards, and that they do not pose a hazard to other people or to the environment. This should include a requirement to monitor risk and to have a response and a business continuity plan that is activated when actual hazard thresholds or warning thresholds are met. The higher the risk, the higher the level of planning needed. The plan should state how a disaster will be avoided given the occurrence of the hazard. Where those businesses are essential to the public, such as infrastructure operators, government should define levels of resilience and safety, and should carry out checks to ensure compliance.

24. Financing & Sustaining
A warning system contributes to the safety, prosperity and wellbeing of the population as a whole and so should generally be funded by government on behalf of the public. Provision of a 24 hour, 365 days per year monitoring, forecasting and warning service is costly and should be justified by regular assessment of its benefits in terms of lives saved, damage avoided, and disruption reduced. Published assessments typically find a benefit to cost ratio of at least 10:1, easily justifying both the initial investment and the ongoing maintenance and running costs. Where specialist warning information is needed for specific industries or infrastructure, the operator needs to specify the requirement and should be expect to bear the cost. However, a government may choose to bear the cost itself in order to make the country or city attractive for investment.

25. Stakeholder engagement
Communities develop their own response to risk from hazards, often over very long periods. The role of disaster risk reduction is to help communities do this more effectively, especially for large impact events that may not have been experienced by living members of the community. To achieve this requires intimate knowledge of how the community currently perceives and deals with risk and then to build on this to reinforce and increase their knowledge of risks and of effective responses where appropriate. These are complex and time-consuming tasks, which may best be carried out by non-governmental organizations involving local community leaders and collaborating with local governments. The role, framework and funding for such engagement should be defined as part of

risk governance framework. Once a warning system is in place, continued engagement is needed to identify and overcome the inhibitors to warning response and to build trust.

26. International cooperation
Disaster risk management is a concern of every country, and depends on data and expertise that should be shared. Such data include risk maps based on satellite data, real time satellite imagery from the International Charter, monitoring centres such as the IOC UNESCO Tsunami Information Centre, and numerical weather forecasts from global and regional modelling centres. Available expertise includes the WMO MHEWS checklist, together with good practice guides for monitoring, prediction, impact-based warning, and media communication. However, each country has responsibility for managing its own risks and authority to define the governance structure within which they will be managed. Local and national capabilities should be supplemented by data and expertise available from outside, wherever this can be done without undermining the integrity of local systems. This is especially the case for MHEWS, for which timely operation is necessary. In order to ensure seamless incorporation of international data and expertise in an MHEWS, the procedures for using them should be clearly defined and exercised regularly. Backup procedures should be defined to allow continued operation if external data connections are lost.