Implementation Plan for Building Capacity in Multi-hazard Impact-based Forecasting and Warning Services in the Caribbean region

ABSTRACT

An Implementation Plan is presented for building capacity in developing and delivering Multi-hazard Impact-based Forecast and Warning Services in the Caribbean region.

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Executive Summary

This implementation plan provides guidance for building capacity in multi-hazard impact-based forecasting in the Caribbean region in a uniform and structured manner through 12 sequential steps. The main purpose of the implementation plan is to support the establishment of people-centred impact-based forecasting and warning services (IBFWS) that operate routinely to provide actionable information on the impact of hazards, in a form that the public, disaster managers and other sectors understand and can take action to protect lives, livelihoods and property. It highlights the essential ingredients of IBFWS and how the capacity for this type of forecasting should be developed.

Impact-based forecasting and warning services focus on translating weather hazards into sector- and location- specific impacts, and the development of anticipatory action[1] to mitigate those impacts. By focusing on impacts, it is expected that those exposed to a particular hazard will have a better understanding of the risk and *will be* more likely to take appropriate action. National Meteorological and Hydrological Services (NMHSs) usually focus on improving observing and forecasting systems and the quality of warnings, which is a necessary but insufficient step to mitigating the adverse consequences of hydrometeorological hazards. NMHSs must also work closely with emergency services, disaster risk reduction and civil protection agencies to share data and to interpret forecasts into a form that results in appropriate actions by everyone. This is a new area for many NMHSs, since it requires extensive knowledge of how meteorology and hydrology affect day-to-day activities, the vulnerability of people, services and infrastructure, and the likely behaviour of people during an emergency. This information is not usually available within NMHSs. Good working relations among all stakeholders, and close cooperation between stakeholders and the service providers, are essential for the successful implementation of this type of forecasting. In turn, the service providers must have access to the best available weather prediction guidance from numerical models to generate timely, accurate and specific meteorological and hydrological forecasts. This is often challenging, but increasingly possible as higher resolution numerical weather predictions become available.

This implementation plan reviews the current efforts by various organizations at the regional and national level in the Caribbean region in developing and implementing impact-based forecast and warning services. It examines the traditional way of producing forecasts based on hazards and hazard thresholds, and the new thinking in approaching forecasts and warnings based on the impacts of hazards, so that the focus is shifting to "*what the weather will do*" rather than "*what the weather will be*". This thinking has already been mainstreamed in some countries in forecast and warning production and communication, while it is at the initial stages of being introduced in some others. Progressing from hazards-based weather forecasts and warnings to multi-hazard impact-based forecast and warning services represents a challenge for many NMHSs and requires a paradigm shift in the way these services are delivered. A key difference between the old and new approaches to forecasting is that many more actors and disciplines will be required to play a role and to collaborate in

[1]The term "anticipatory action" is used in this document for forecast-based action, also referred to as "early action" or "risk-informed action" or "forecast-based financing" when a forecast threshold triggers release of funds necessary for rapid action. In taking "anticipatory action", the intended result is an action in response to the warning, as opposed to response to the impact.

producing and delivering impact-based forecasts and warnings. A major partner is the disaster risk management agency in each country, however in a multi-disciplinary area such as impact-based forecasting, expertise and skills in social sciences, vulnerability assessment and Geographic Information System (GIS), are required in addition to meteorology and hydrology in a way that has not been practiced before.

While impact-based forecasting focuses on weather and water related hazards, it is possible and indeed desirable particularly in the Caribbean region, to incorporate many other hazards including geophysical (e.g., earthquakes and tsunamis), technological (e.g., road and marine transport) and biological (e.g., epidemics) in the implementation of impact-based forecast and warning services. Creating a single Multi-Hazard Impact-based Early Warning Services and Systems "MHIEWS" capable of incorporating all potential risks has advantages from the perspective of both disaster managers and those at risk. Since multiple threats can occur simultaneously – for example, earthquakes, volcanic eruptions, COVID and tropical cyclones – managing technical, human and financial resources effectively helps avoid compounding the risks.

Abbreviations

CARICOM	Caribbean Community
CDEMA	Caribbean Disaster Emergency Management Agency
CIMH	Caribbean Institute for Meteorology and Hydrology
CMO	Caribbean Meteorological Organization
DRM	Disaster Risk Management
EP&R	Emergency Preparedness and Response EP&R
EPS	Ensemble Prediction Systems
GIS	Geographic Information System
IBF	Impact-based Forecasting
IBFWS	Impact-based Forecasting and Warning Services
ICT	information and communication technology
IBFWS	Impact-based Forecast and Warning Services
MHIEWS	Multi-Hazard Impact-based Early Warning Services and Systems
NDMO	National Disaster Management Organization
NMHS	National Meteorological and Hydrological Service
NHP	Natural Hazards Partnership
NWP	Numerical Weather Prediction
NWS	National Weather Service
PWS	public weather service
WMO	World Meteorological Organization

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1 The purpose and application of this implementation plan

The purpose of this document is to provide guidance for building capacity to develop and implement multi-hazard impact-based forecast and warning services and systems (MHIEWS) in the Caribbean region in a uniform and structured manner. This implementation plan highlights the value of introducing and enhancing impact-based forecast and warning services and outlines the steps and tools needed to develop these products and services, ranging from understanding risk to producing, issuing, and verifying fit for purpose impact-based forecasts and warnings. The role of different organizations in this endeavor, and the type and level of effort, including training, comprise key parts of the document. For this purpose, the guidance material is designed for everyone working in IBF, early warning, and early action, including technical staff in NMHSs, disaster risk management, as well as humanitarian and development agencies. The plan draws extensively on the current body of knowledge and experience gained in building capacity in the production and delivery of impact-based forecasts and warning services in different countries.

2 Introduction

All disaster risk management or emergency preparedness and response (EP&R)[2] systems include *early warning* as an essential component required to facilitate effective *early action*. It is recognized that warning services are only as good as the EP&R actions they catalyse. Effective early action is both an essential part of any warning system and a critical component of any EP&R system. If a warning is sounded, and no one takes the action that the warning was intended to trigger, then the warning system has failed. Figure 1 shows the EP&R system including early warning systems. The five core components of emergency preparedness and response include legal and institutional frameworks, information, facilities, equipment, and personnel.

Figure 1. Emergency Preparedness and Response System Core Components[3]

[2] It is important to note that when referring to impact-based forecasts, the term *response* is in reaction to the *warning* and not the *impact*.

[3] Rapid Diagnostic User Guide-Emergency Preparedness and Response Systems (The World Bank)-2017

Strengthening multi-hazard impact-based meteorological and hydrological forecasting and early warning systems and services demands national level efforts, on the part of all involved organizations, as described in the WMO Guidelines[4]. Impact-based forecasting provides the information needed to act before weather and climate hazards turn into disasters, to minimise the social and economic costs of those potential disasters.

In the Caribbean region different severe weather and geological hazards are the cause of flooding, droughts, landslides, earthquakes, and volcanic eruptions, which adversely impact the lives, livelihoods, and property of a large number of the population in the region.

Impact-based probabilistic forecasts are routinely produced in many advanced NMHSs. Capabilities to produce, translate and communicate these forecasts to users are beyond the basic skills taught to weather and hydrological forecasters in most of the developing countries' NMHSs. However, there is no reason why with a sound strategy to access the products of the advanced global centres, and use of their own observation data together with a realistic capacity building plan, the Caribbean countries should not be able to equally benefit from progress in this area.

The Caribbean Institute for Meteorology and Hydrology (CIMH), Caribbean Meteorological Organization (CMO), and the Caribbean Disaster Emergency Management Agency (CDEMA) are the three main agencies in the region whose participation will be essential in building this implementation plan. It is acknowledged that much work has been done in the Caribbean by these regional entities. The CDEMA Model National Multi-Hazard Early Warning System (MHEWS) Policy and Adaptation Guide provides the framework for developing national multi-hazard *impact-based* early warning systems, and CIMH and CMO have advanced the development of impact-based forecasting in the region.

With a view to levelling up the different stages of capacity in the Caribbean, a series of webinars have been developed for practitioners from different countries in the region based on this implementation plan. While webinars will focus on developing materials, organizing, and conducting training activities, the focus of the implementation plan is on describing principles, benefits, and challenges in the development of impact-based forecast and warning services to guide these activities in the region.

3 Overview

3.1 User Requirements

Identifying the users of forecasts and warnings is key to the development and operational delivery of impact-based forecast and warning services. Users of impact-based forecasts and warnings cover a wide range and for this reason it is not always possible to develop forecasts or warnings which will satisfy all of their requirements and respond to challenges. Some of the typical users of these forecasts and warnings are listed below. This list is not exhaustive.

- General public
- National and local government ministries, departments and offices
- National and local Disaster Risk Management and First Responders including police, army, firefighting services and Red Cross/Red Crescent
- Media

[4] WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services (WMO-No.1150)-2015

- Public services including transport, hospitals, schools, water and sanitation, communication networks, public works
- Business community including commerce, tourism, agriculture and fisheries
- NGOs and humanitarian community

It is important to get to know what each of these user groups expects from impact-based forecasts and warnings. This can be done through workshops, surveys, and interviews to gather feedback and suggestions from potential users of forecasts and warnings.

Some of the questions that could be used to identify the users and their needs are listed below[5]. This list could be expanded as may be needed.

- Who is requesting impact-based forecasts and warnings?
- Who could apply and benefit from these forecasts?
- Who is using the forecasts for decision-making or for taking early action?
- What forecast and warning information is currently being used by the various users?
- How is forecast and warning information used in practice?
- What challenges do users face at the onset of and during a hazardous event?
- What risks or impacts are users trying to mitigate or reduce?
- How can forecasts and warnings provide appropriate information to enable informed decision-making and trigger anticipatory action?
- At what spatial scale do users need forecast and warning information in order to act effectively?
- What lead time do users need in order to prepare for an event?
- What would be the consequences of false alarms?

While it is acknowledged that weather and climate information is one among many kinds of information that is needed for making informed decisions when faced with a hazard, it is useful to know if users are aware of the existing products and services of NMHSs, how they can access and use these products in their decision-making process, and how these can be adapted to meet the user requirements for impact-based forecast services. It is equally important for NMHSs to acknowledge what their current capacities are and whether they can respond to all requests for such forecasts and warnings. It is very likely that the service providers would need to develop new skill sets in order to respond to expanding requests.

3.2 What is meant by Impact-Based Forecasting?

There is currently an uneven understanding among different actors (meteorologists, hydrologists, disaster managers and other national authorities as well as international organizations and individual experts) of the meaning of impact-based forecasting and early warning. This has resulted in confusion as to the approaches and tools that are needed to implement and communicate the outcome of this type of forecasts and warnings.

Impact-based forecasting was largely the invention of the meteorological community which recognized that warnings based exclusively on *what the weather would be* are difficult to understand and translate into action. This led to a focus on *what the weather would do*. At its

[5] The Future of Forecasts: Impact-based Forecasting for Early Action. Met Office, IFRC 2020

simplest, this means the translation of hazard vocabulary into clear information about the likely impact of the hazard. Supplementing the forecast of “60 k/h winds” with the likely impact on homes, the risk of uprooting trees, damaging roofs, for example, would raise awareness of the actual threat to life and property. Causal relationships are based largely on past events and reports of damage. While this offers an improvement on weather warnings alone, these basic impact-based forecasts are not necessarily sufficiently specific or targeted to individual circumstances to improve the reaction of those at risk. Such warnings don’t necessarily result in people taking early action to protect themselves from serious harm. More quantitative impact-based forecasts explicitly take into consideration location-specific vulnerability – height of flood waters in a specific location; quality of buildings and bridges to withstand wind, mudslides, flood water; the resilience of critical infrastructure such as electrical power, water and sanitation systems; the resilience of hospitals, schools, and other public services, as well as the capacity of government for early action.

Overcoming the limitations of warnings based on vulnerability of critical infrastructure alone, requires impact-based warning services to focus more on the social determinants of vulnerability – health, gender, income, education, psychological barriers, ethnicity, community behavior, and so on. Acquiring data on these factors goes far beyond the responsibility of those forecasting the physical hazards and involves many other contributors. Impact-based warnings based on social determinants, in addition to the vulnerability of infrastructure, are likely to significantly improve the preparedness and response of those at risk because the warnings can be tailored to individual or community needs. Different thresholds of vulnerability require different forecast triggers for anticipatory action. There is plenty of evidence to support the need to develop differentiated warnings based on gender, age, ability, income and that these factors determine the level of impact of the threat and type of warning messages communicated.

There are several obstacles that must be addressed. These include overcoming institutional barriers that inhibit the creation and use of a common platform for multiple agencies to work together collaboratively; establishing roles, responsibilities and implementing effective operating procedures; acquiring and maintaining current vulnerability databases; relating diverse vulnerability data to hazard risks to create impact-based forecasts; and communicating warnings in a way that encourages effective action by those at risk.

This advanced impact-based system is a multi-institutional activity and no longer the sole responsibility of the forecasters whose main responsibility remains accurate and timely forecasts of physical hazards. Since disaster management agencies often maintain GIS vulnerability data bases, it may be appropriate that they have the responsibility to create impact-based forecasts and warnings, or that this is a joint responsibility of several entities. In a multi-hazard context, disaster managers would be the logical focal points for the integration of all critical information and intelligence (Figure 2).

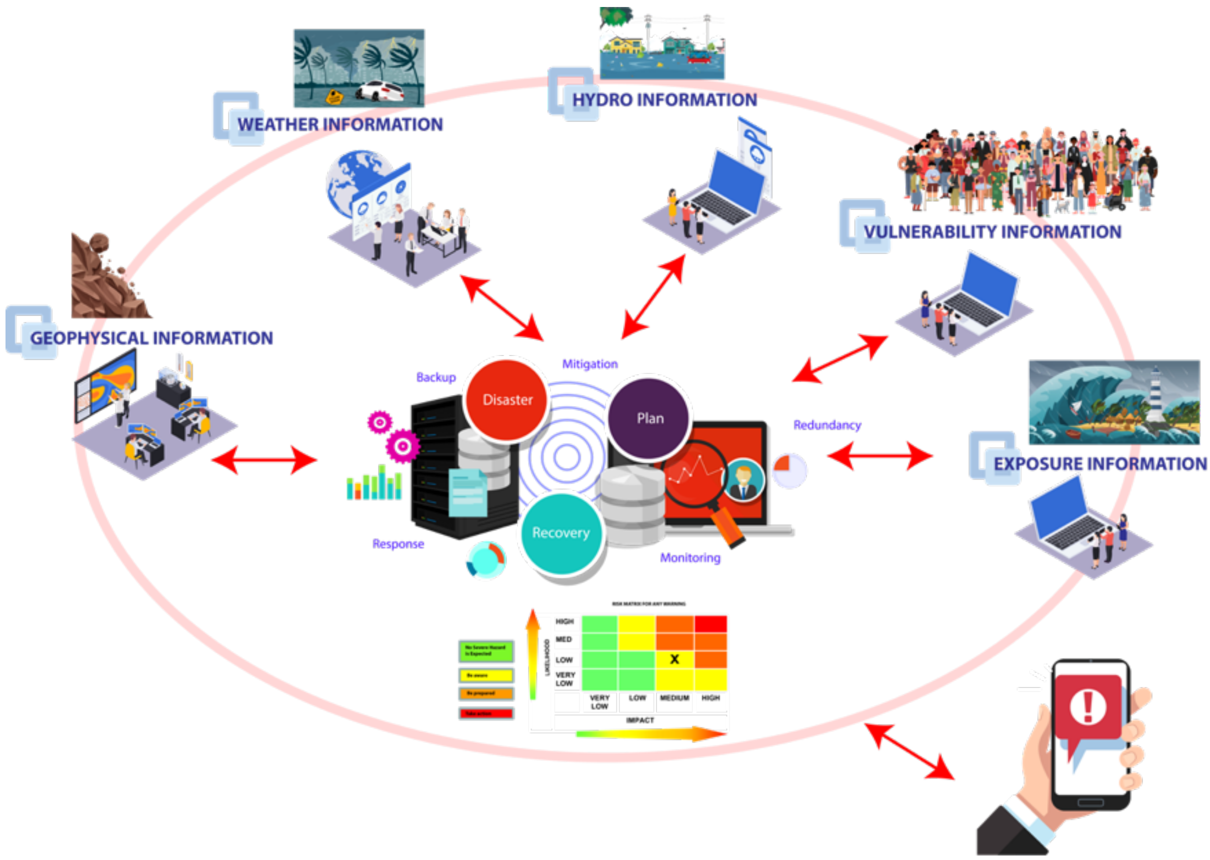

Figure 2 Schematic of Multi-hazard impact-based forecast, warning, and decision support system[6]

The timing and location of activities, for example farming and fishing, which expose people directly to hazards such as floods, winds, lightning, and waves, need to be quantified so that impact-based forecasts are tailored to those at risk. In many countries, these data are more and more routinely acquired as a part of extensive risk mapping projects. This has a number of implications for the future of NMHSs; in particular, on the skills required to understand how the weather impacts society and to develop the necessary tools to inform users more effectively.

Exposure is a necessary, but insufficient factor in forecasting risk. It is possible to be exposed but not vulnerable, for example, by living on a floodplain but having sufficient means to modify building structures and behaviour to mitigate potential loss. COVID is another good example of vulnerability and exposure. A certain age group, for example the elderly, is highly vulnerable but safe if not exposed to the threat. High exposure of less vulnerable people can also have serious risks.

However, to be vulnerable to a hazard, it is also necessary to be exposed[7]. Knowledge of individuals' exposure to a hazard is limited at present. Early action decisions are made based on general knowledge and experience, rather than on knowing the specific circumstances of everyone at risk. Hence even impact related warnings remain quite generic, with the responsibility on the individuals to assess their exposure and vulnerability to the hazard, or on civil protection to act on behalf of those at risk. Lack of understanding of exposure may contribute to poor response to an accurate warning. Thus, a logical progression to a final step

[6] David. P. Rogers (2021)-WB presentation to the South Asia Hydromet Forum

[7] WMO Guidelines on Multi-Hazard Impact-based Forecast and Warning Services. WMO-No. 1150 (2015)

would be the evolution from impact-based to impact forecasts where exposure (time and space dependent) is explicitly included in the prediction system.

Increasingly, those affected by hazards are demanding more than statements of expected weather conditions from their meteorological and hydrological service providers. It may be argued that forecasting disaster risk and hydrometeorological impacts is beyond the responsibility of meteorologists and hydrologists. This is to some extent true in that the information and data that are required for impact-based forecasts and warnings go beyond the meteorological and hydrological data that are at the disposal of those professionals. However, since the risks associated with extreme weather events change and evolve as the weather situation evolves, NMHSs should be actively involved in predicting impacts of hazards since they are constantly monitoring these evolutions.

The NMHS, however, may or may not be responsible for issuing the impact-based warning. In some countries this may be the responsibility of the disaster management agency or another designated authority. In all cases, however, there should be very close and continuous cooperation among the responsible agencies including the NMHS. This is particularly important where the hazardous situation may evolve rapidly, escalating the threat and the need to update warning information frequently.

It is one thing for an NMHS to be informed about, and to introduce the concept of impact-based forecasting in its own environment, but it is quite another thing to scale up that introduction to initiate the involvement of other national actors. This requires a significant change in NMHSs' operations, responsibilities, training, and partnerships with other national actors. The expected benefit would be a significant increase in the capacity of communities and different sectors to take appropriate action to protect families, livelihoods, and property, and therefore a reduction in disasters.

In many places, meteorological and hydrological hazards are likely to become more dangerous due to climate change. This is certainly the case in the Caribbean region. Existing community experience and knowledge alone will not be sufficient to handle these new threats. However, the capacity to cope can be improved when the public are consulted and engaged in the development of warning services that are adapted to their needs.

3.3 Multi-hazard early warning systems

Most efforts to improve multi-hazard impact-based early warning services and systems (MHIEWS) focus on achieving an advanced level of service. This requires investment in all aspects of the system from improving basic forecasting, gathering vulnerability data, calculating impact-based forecasts, and communicating warnings to those at risk and to those responding to hazardous situations. Figure 2 highlights several critical factors:

- A common ICT backbone shared among all contributors
- The potential for multiple hazards to occur simultaneously
- The need for integration of multiple sources of information about hazards, vulnerability, and exposure
- The need for two-way communication between all contributors and between the service and the users of the service.

Most of these efforts focus on weather and water related hazards. Not yet evident, but implied, is the possibility of incorporating many other hazards including geophysical (e.g., earthquakes and tsunamis) technological (e.g., road and marine transport) and biological (e.g., epidemics). Creating a single MHIEWS capable of incorporating all potential risks has advantages from the perspective of both disaster managers and those at risk. Since multiple threats can occur simultaneously – for example, earthquakes, volcanic eruptions, COVID and tropical cyclones – managing technical, human and financial resources effectively helps avoid compounding the risks. From a user viewpoint, implementing a common alerting protocol allows people to assess their risks within a single impact-based framework that uses consistent symbols, words, and color-codes focused on the impact of the threat rather than being overly focused on the individual hazard[8] – the impact of a tsunami and a storm surge may be the same, for example. The objective is for those at risk to grasp the severity of the situation quickly and take the appropriate early action. Since some hazards are rare and others frequent, the multi-hazard approach helps maintain a continuous level of awareness of risk.

3.4 How does Impact-based Forecasting differ from traditional forecasting?

The simplified hydrometeorological value chain is shown in Figure 3.

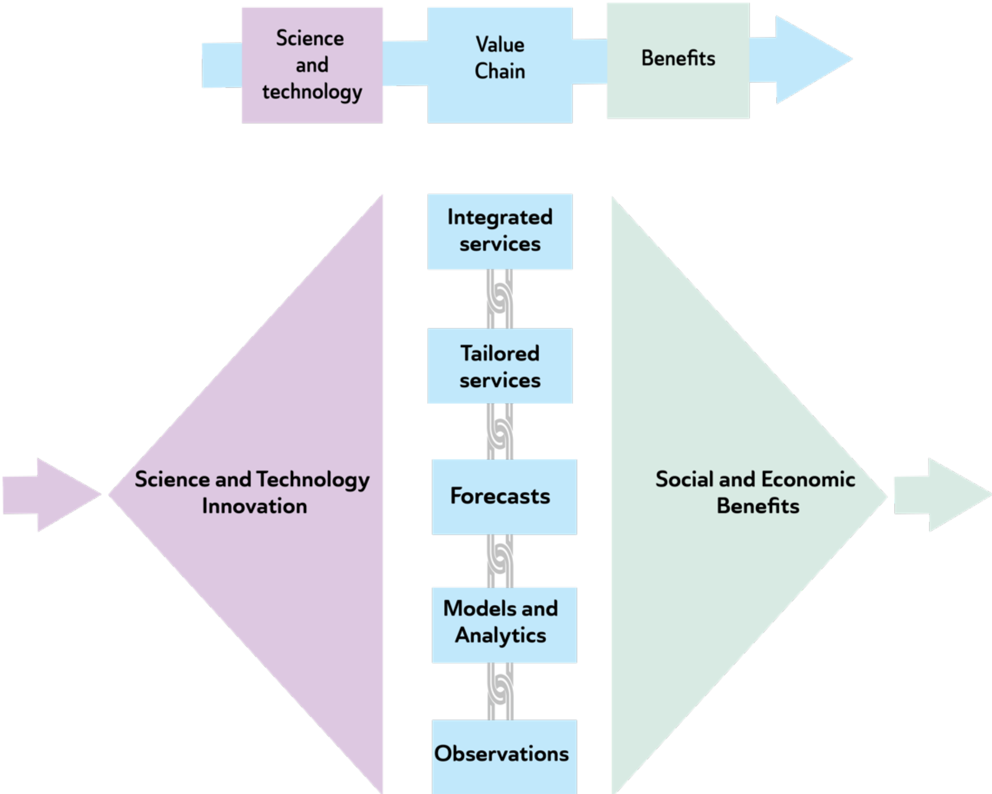

Figure 3 The simplified hydromet value chain[9]

Unlike objective weather, climate, and hydrological forecasts, which can be developed with one or two disciplines and limited actors, impact-based forecasts require access to a wide range of new data including social information, livelihood information, resilience of infrastructure systems and services.

[8] See, for example, Meteoalarm, which provides a common warning system across multiple countries– https://meteoalarm.org/en/

[9] Thorpe, Alan, and David P. Rogers, 2021: Creating Value in the Global Weather Enterprise. World Bank, Washington, DC

Consequently, the box representing observations in Figure 3 must be adapted to include these additional data sources. IBF also requires the Numerical Weather Prediction (NWP) system to be probabilistic rather than deterministic since actions must be taken based on risk.

Hazard-based forecasts and warnings often use hydrometeorological thresholds based on the magnitude of the hazard as the trigger to issue a specific forecast or warning. Although thresholds do not need to be explicitly communicated within impact-based forecasting (unless requested by the user), hydrometeorological thresholds are important within the impact-based forecasting process. Identifying an appropriate hazard threshold beyond which impacts are possible, or the level of impact to trigger early action, can be a key piece of information for the risk assessment process. Analysing past events helps identify correlations between the magnitude of a hazard and the impact. Many hazards have multiple thresholds at which impacts occur. Thresholds will vary based on area affected, topography, ground and soil conditions, time of day, season, resilience of infrastructure, health of the local population, types of land use, etc. Adjusting trigger thresholds, possibly on an event by event basis and based on changing user requirements may be necessary. For impact-based forecasting, thresholds must be defined from assessments of the magnitude of hazard that results in specific impacts. This means that it is important to understand which impacts are possible, where they may occur, and what can be done to prevent or minimise the impacts.

In IBF, the forecast generation process is a combination of objective forecasting and impact-related information. Warnings will also consist of both hazard and impact warnings. The latter are often jointly issued by NMHSs, Disaster Risk Management (DRM) and other related agencies.

Tailored services remain an important responsibility of NMHSs in their role as public weather service advisors to other MHIEWS collaborators and to end-users of the system.

Integrated services (whereby actual hydromet data is provided to a user sector who combines it with its own data to produce the specific products that are needed by the sector) improve decision processes in reaction to hazard warnings coupled to their own impact assessments. A MHIEWS, based on advanced impact-based forecasts, is an example of an integrated service – a link in the hydrometeorological value chain[10] where meteorological and hydrological data are amalgamated with other data to provide a new unique derivative service. A comprehensive MHIEWS isn't the purview of a single agency but depends on close collaboration between many actors and as noted above, this is probably the most difficult challenge for many NMHSs as impact-based forecasting evolves from a basic to an advanced level, and overall responsibility shifts to other entities.

Many more actors (section 4.6), including communities, play a role through their response to impact-based forecasts and providing feedback to the forecasters. Users of the information drive the requirements for information and therefore receive it in a form they are expecting and can understand.

3.5 Current approaches to IBF: 3 examples

The examples below broadly represent different current approaches to IBF. While there may be variations in the details of each approach, it should be noted that they all follow common

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[10] Thorpe, Alan, and David P. Rogers, 2021: Creating Value in the Global Weather Enterprise. World Bank, Washington, DC

principles of using various data and tools to turn hazard information into impact information to inform decision making and early action. They aim to address the need to integrate human, economic, cultural, risk and uncertainty dimensions for weather-related events that impact safety and the economy into actionable forecasts. By understanding socio-economic impacts of the hazards, those at risk can be targeted and information can be communicated to them in ways they can understand and respond to.

3.5.1 WMO Guidelines

The WMO Guidelineshttp://library.wmo.int/pmb_ged/wmo_1150_en.pdf on Multi-hazard Impact-based Forecast and Warning Services (WMO-No. 1150) define three ways of preparing forecasts and warnings – weather forecasts and warnings, which include information about the hazard only; impact-based forecasts and warnings, which include information about the hazard and vulnerability to that hazard; and impact forecasts and warnings, which include information about the hazard, vulnerability and exposure.

Vulnerability and exposure may be defined in several ways – for the present purpose and in the context of meteorological and hydrological hazards these are defined as follows (Figure 4).

Vulnerability: The susceptibility of exposed elements, such as people, their livelihoods and property, to suffer adversely when affected by a hazard. Vulnerability is related to fragilities, weaknesses, deficiencies, or lack of capacities that favour adverse effects on the exposed elements. Vulnerability is situation-specific, interacting with the hazard to generate disaster risk.

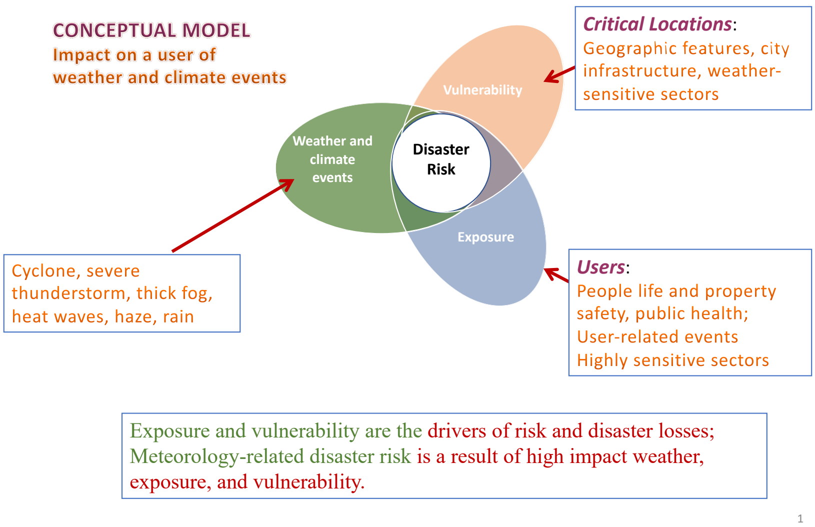

Figure 4 Disaster risk as a relationship between hazard, vulnerability, and exposure

Exposure: Refers to who and what may be present in an area in which hazardous events may occur. If the population and its economic resources were not located in (exposed to) a potentially dangerous setting, no risk would exist

Exposure is a necessary, but insufficient factor of risk. It is possible to be exposed but not vulnerable, for example, by living on a floodplain but having sufficient means to modify building structures and behaviour to mitigate potential loss. However, to be vulnerable it is also necessary to be exposed. Exposure is time and space dependent. An example of exposure related to geographic location would be a vehicle driving across a bridge during a windstorm.

To highlight a situational example, a crane would have a much higher exposure during the same windstorm than would a car at street level. An example of exposure due to timing would be a windstorm that strikes during the peak of an urban rush hour which might result in a much higher exposure factor than if it were to hit an unpopulated rural area in the middle of the night.

Knowledge of individuals' exposure to a hazard is limited at present. Anticipatory action decisions are made based on general knowledge and experience, rather than on knowing the specific circumstances of everyone at risk. Hence even impact related warnings remain quite generic with the responsibility on the individuals to assess their exposure and vulnerability to the hazard, or on civil protection to take action on behalf of those at risk.

Disaster Risk: The probability and magnitude of harm possible to humans, their livelihoods and assets resulting from exposure and vulnerability to a hazard.

Increasingly, it is realistic to expect communication tools and social media to advance to a point where personalized warnings will be the norm in developed and developing countries alike, and direct feedback from people will be possible as they take action to reduce their exposure. This would be the final step in the evolution from impact-based to impact forecasts where exposure (time and space dependent) is explicitly included in the prediction system.

However, the focus of this implementation plan is primarily on developing **impact-*based*** forecast and warning services, which mainly consider the **hazard and vulnerability to the hazard** with more generic assumptions about exposure. It is of course necessary to know which populations, infrastructure, natural resources, or assets are exposed and where they are. For example, households on the wrong side of protective embankments or in river basins a long way from high ground are particularly exposed to floods which may impact them more severely than if they had the protection of secure infrastructure.

The evolution of weather forecasts to impact forecasts is summarized in Table 1, which is adapted from the WMO guidelines cited above, for the specific case of a tropical cyclone event.

Table 1 Evolving Warning Paradigm using a tropical cyclone as an example

Type of Forecast and warning	**Description of forecast or warning**	**Factors incorporated**
General Forecast	In the next 24 hours, the tropical cyclone is likely to impact or has already had an impact on the target area.	Hazard
Warnings with fixed thresholds	In the next 24 hours, the tropical cyclone is likely to impact the target area. Average wind speeds of 118-133 km/h on- and off-shore or gusts of 150-166 km/h; this condition is to continue	Hazard
Warnings with user defined thresholds	Rainfall accumulations of 200 to 300 mm expected, with a high probability of the overflow of drainage system in District A *(This warning would be issued by a municipal authority only)*	Hazard, Vulnerability

Type of Forecast and warning	Description of forecast or warning	Factors incorporated
Warnings with spatial and/or temporal variations in thresholds	Spatial differences: Tropical cyclone warning, gusts of 150 km/h generally, with local gusts in District B expected to exceed 180 km/h Temporal differences: Tropical cyclone warning – rainfall accumulations of 200 to 300 mm expected tomorrow afternoon during the peak rush hour	Hazard, Vulnerability
Impact-based warning	Rainfall accumulations in excess of 200 mm are expected tomorrow, expect road closures and rerouting of traffic to avoid flood prone areas. *(Here the impact is road closures)*	Hazard, Vulnerability
Impact warning	Based on the risk of flooding along your normal commute from workplace to home tomorrow, follow the alternative route… flexible time will be implemented – Based on your usual work schedule, leave work at least 1 hour earlier than normal to avoid significant delays. *(Here the information is intended to reduce exposure, while still permitting productive activity)*	Hazard, Vulnerability, exposure

Evolution of warnings from hazard-only to spatial threshold and finally to impact-based is illustrated in Figures 5-7[11].

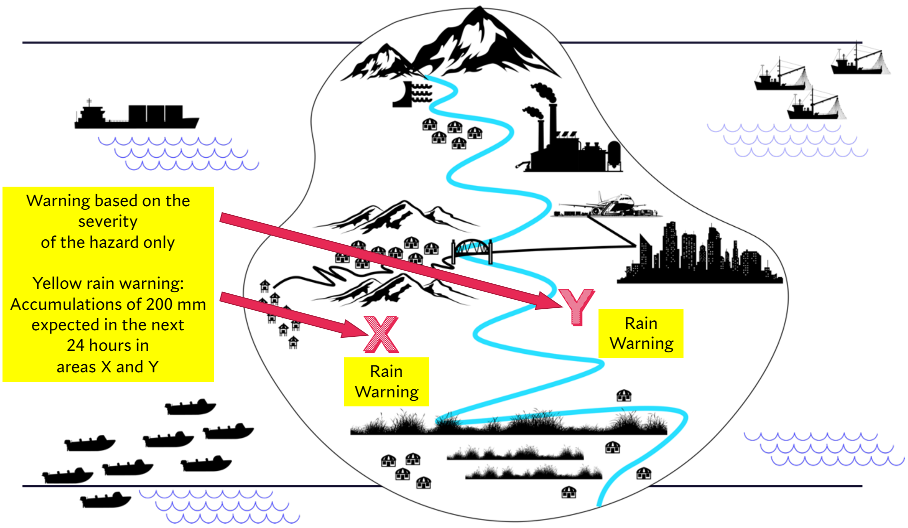

Figure 5. Warnings based on the severity of the meteorological hazard only

[11] David. P. Rogers (2021)-WB presentation to the South Asia Hydromet Forum

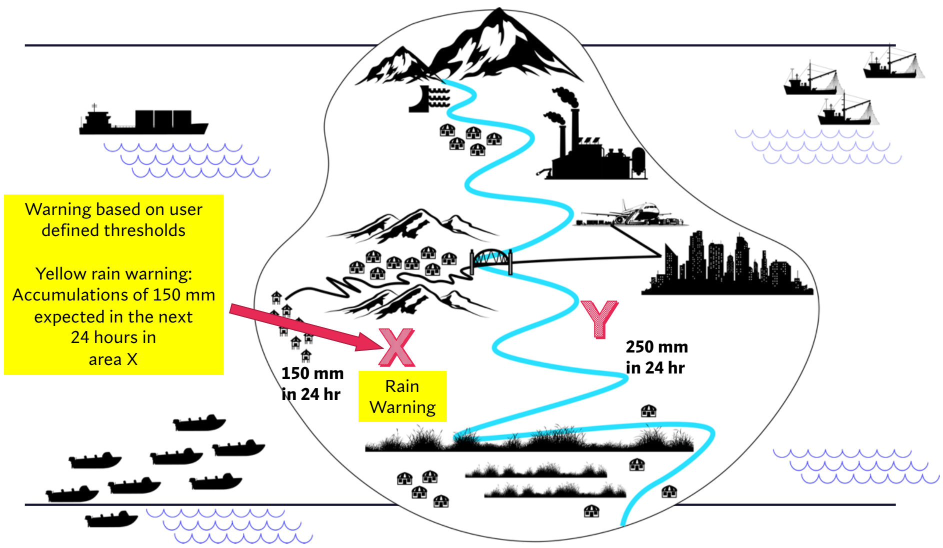

Figure 6. Warning takes into account the spatial variation of thresholds. In the example, the warning is only given for location X because the rainfall is expected to exceed this location's threshold. In this case, thresholds are defined by road authority and emergency management.

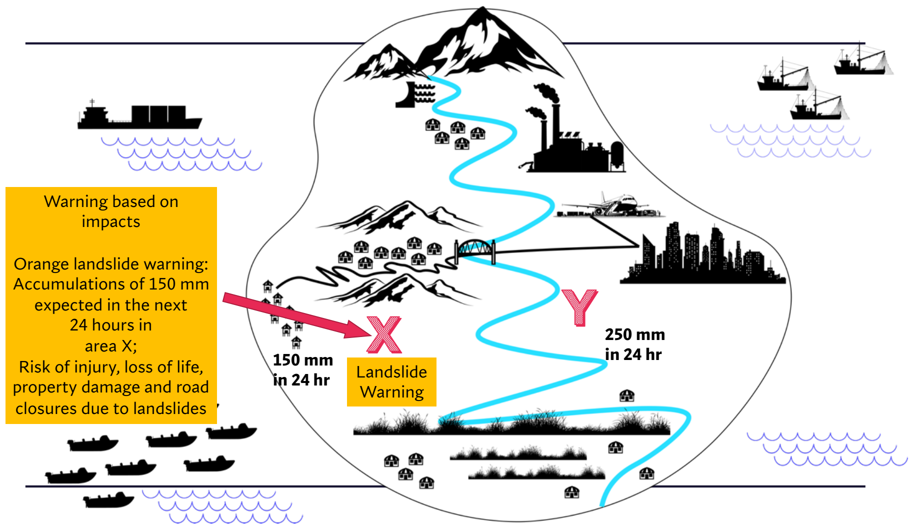

Figure 7. Impact-based warnings. In this case, the warning information makes specific reference to the likely impact

The WMO Guidelineshttp://library.wmo.int/pmb_ged/wmo_1150_en.pdf on Multi-hazard Impact-based Forecast and Warning Services (WMO-No. 1150-Part II) expand on some of the concepts introduced in the original Guidelines (2015), particularly communication, and verification aspects of IBF. These Guidelines also highlight the major gaps that can prevent countries from developing effective IBF services including deficiencies in impact data and lack of impact databases, technical standards, cross-border exchange of impact data, verification methods and understanding user needs.

3.5.2 Weather Ready Nations (WRNs)[12]

A notable effort to evolve from forecasting the weather to addressing the impacts of the weather is the international Weather-Ready Nations (WRNs) program initiated by the US National Weather Service (NWS) and United States Agency for International Development/Bureau for Humanitarian Assistance (USAID/BHA). Recognizing the important role of impact-based forecasting and early warning services in disaster risk reduction, the focus of WRNs is to strengthen capacity of NMHS and DRM agencies with the goal to foster preparedness in individuals, groups, and institutions in mobilization (wanting to act) and empowerment (knowing what to do). Examples of countries that are currently implementing this program include Barbados, Costa Rica, El Salvador, Guatemala, Indonesia, Jamaica, The Bahamas, Grenada, Saint Lucia, Dominica, St Vincent and the Grenadines, Fiji, Palau and South Africa.

Specifically, the goals of the WRNs program include production of local-scale, relevant, impact-based forecasts and early warnings that can be made into accurate, timely and easily understandable weather and climate information services which can, in turn, be easily integrated into decision-making processes. This is achieved through a four-phase approach[13] described below, that defines the What, Where, When and Early Actions that relate to the specific hazard and includes the information in the forecast and messaging. Based on this four-phase approach, the introduction of impact-based forecasting in an NMHS and DRM in the Caribbean region may follow these steps:

Phase One: Developing matrices for impact-based forecasting

The NMHS and DRM agency will need to work together to understand what information they need to improve decisions that protect lives, livelihoods, and property and how they will disseminate reliable and specific forecasts. They will then jointly develop a risk matrix (Figure 8) that illustrates the level of impact and the likelihood of occurrence for a specific hazard. Development of this matrix is complex and is explained in detail in section 5.7. Using the matrix, the NMHS will be able to communicate the probability or likelihood of a potential hazard or multiple hazards. The DRM agency will use that information to determine the severity of impacts.

[12] WRN & CIMH/CMO have been referring to this program in the Caribbean as Weather and Climate Ready Nations

[13] *WMO Bulletin Vol 67 (2) 2018. Impact-Based Forecasting and Warning: Weather Ready Nations.*

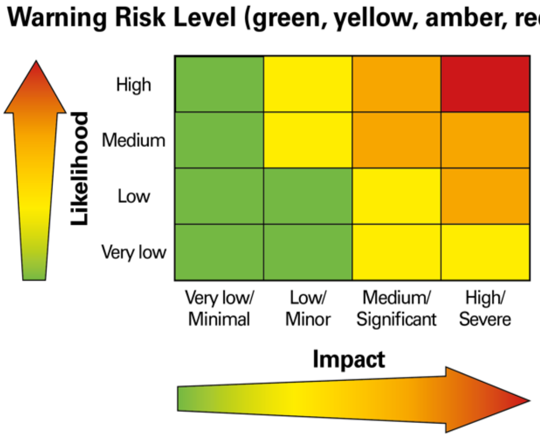

Figure 8 Risk Matrix

The two agencies will need to collaborate to identify how the likelihood of impact of a hazard relates to the severity of the impact. The experience of the DRM agency in responding to disaster situations provides the NMHS with an understanding of how the weather hazard can interact with the vulnerabilities of infrastructure (buildings, roads, etc.), people and services, and the exposure of the population and their livelihoods to the hazard.

A final component of this phase is the inclusion of advisory or early action tables. These tables will provide guidance on what advice will be provided by the NMHS and the DRM agency when a severe weather event is likely to occur. Using the colour code shown in Figure 8, the advice would be based on a combination of potential impact and likelihood. For a group of hazards as shown in Figure 9 (rain, wind, snow, surface ice and fog), the advice table may be green, indicating no severe weather is expected and no action is needed, yellow indicating there is low likelihood/impact (Be aware), orange indicating there is a medium likelihood/impact (Be prepared) and finally red indicating a high likelihood/impact (Take action) which most likely will require evacuation of the population.

Figure 9 Graphic representation of an advisory table

Phase Two: Technology and communication tools

As already indicated, the implementation of a multi-hazard impact-based forecasting and early warning approach requires new types of meteorological and hydrological forecasts and warning information. New visual ways of presenting information, including maps, graphics and weather symbols are also needed. This will require either the development of a new web-based display system or the use of existing software that may be available to both agencies. Tools that can combine high resolution numerical modelling, hydromet observations, as well as data on exposure and vulnerability will be needed to produce tailored impact-based forecasts and warnings. Substantial training of NMHS and DRM staff, in using such tools to produce impact-based forecasts, and their interpretation for users, is essential to address specific weather-information needs of various users.

Impact-based forecasting and early warnings require a wide variety of dissemination methods, such as mobile phones, SMS, radio, television, web page, Facebook, Twitter, WhatsApp, etc to make sure the information is accessible to a wide range of the population.

Phase Three: Development of standard operating procedures

Standard Operating Procedures (SOPs) are intended to help increase and guide early action in case of severe weather events and their impacts. SOPs outline what actions need to be taken by whom and when, whenever there is the likelihood of a potential or impending severe weather event.

SOPs provide a structured framework for the initiation of early actions to mitigate the impacts of severe weather with a focus on three key areas:

- Timely information on the hazard and analysis of its potential impacts
- Strengthened coordination among partners to implement early action in a timely manner
- Improved early action and preparedness planning.

The target audience for SOPs are the NMHS and DRM agency and other relevant partners at local, regional and national levels.

Phase Four: Training and outreach

A key component in the sustainability of an impact-based forecasting programme is building the capacity of the NMHS, DRM agency and other relevant entities. In addition to training these agencies in scientific and technical areas related to impact-based forecasting, training should also be provided in communication and teamwork, and user education in understanding the types of severe weather events, their potential impacts, and the importance of community planning for these hazards.

Close operational cooperation among NMHS, DRM and other stakeholder agencies, for example agriculture, transportation, health, water resources and communities, is an essential element of effective impact-based forecasting and early warnings. This requires a high-level commitment from the agencies involved to work closely together to share data, information, expertise and responsibility. It also requires the development of operational implementation plans by each of the collaborating agencies.

3.5.3 Tamil Nadu System for Multi-Hazard Potential Impact Assessment, Alert, Emergency Response Planning and Tracking (TNSMART)

The third example is from Tamil Nadu in India. Tamil Nadu is exposed to various seasonal hazards such as heavy rainfall, floods, landslides, cyclones, storm surges and droughts and non-seasonal hazards such as sea erosions, forest fires and tsunamis.

TNSMART is a web-based operational decision-support system for policy makers, disaster managers and communities to manage disaster risks, by transforming generic weather forecast data into action-relevant, impact-based early warning information. TNSMART (Figure

10) integrates historical-data-based vulnerability mapping with rainfall/storm surge forecast products to assess potential flood scenarios (predictive analytics) based on learnings from past impacts (descriptive analytics). It can then evaluate and disseminate forecast-based alerts and prescribe impact-management options to ensure better preparedness for risk management (prescriptive analytics).[14]

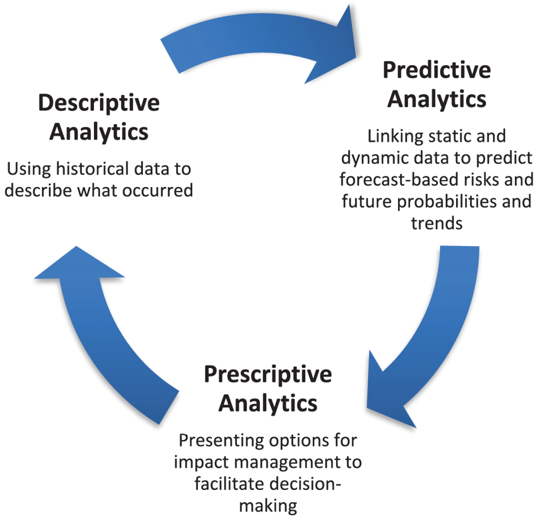

Figure 10 The concept of TNSMART

TNSMART consists of 11 modules as shown below.

[14] TNSMART: a web-based decision support system for strengthening disaster management

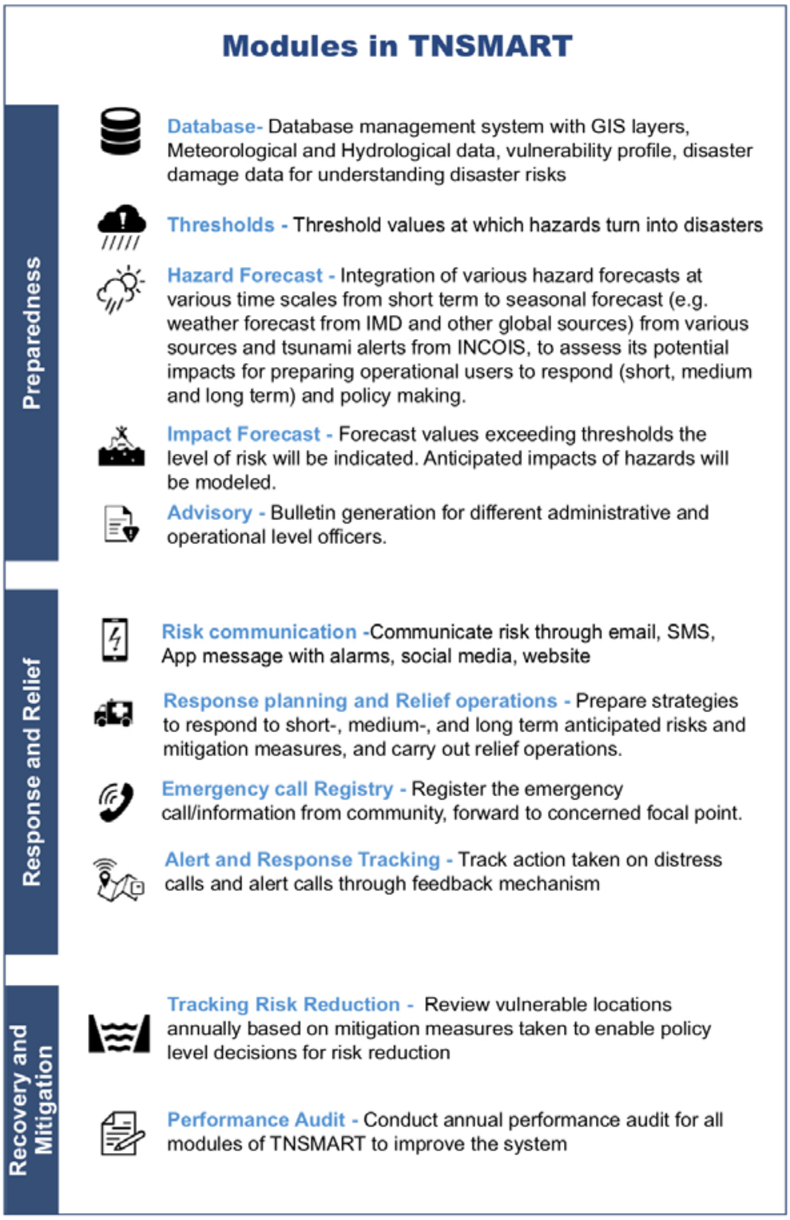

Figure 11 Modules in TNSMART

Brief explanation is provided for a number of the modules.

Database. A one-step comprehensive database to support various stakeholder needs in disaster preparedness, response, relief, recovery, and mitigation is a key feature of TNSMART (Figure 12).

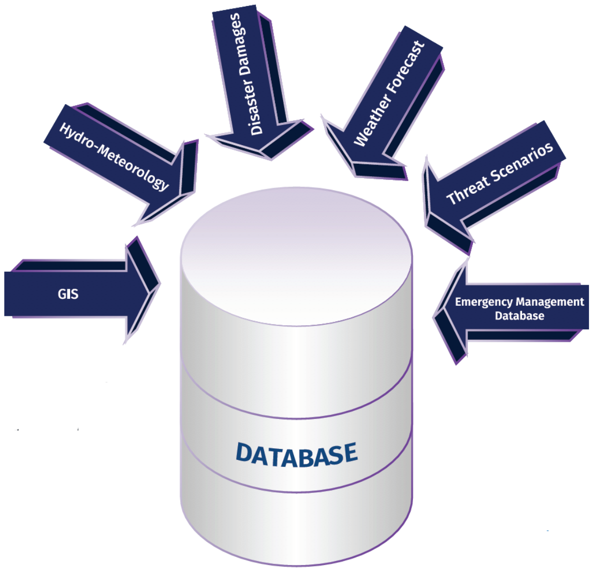

Figure 12 The TNSMART database

For instance, the disaster database provides valuable information for identifying low-lying areas prone to coastal and inland flooding, and evacuation locations in elevated areas. Historical data confirms the findings of Digital Elevation Models (DEM) based on information about historical flood events (where, what, when and how). Weather forecasts are a dynamic dataset providing information on anticipated weather conditions geographically. When connected to historical data, forecasts can help identify areas vulnerable to flooding. Simulation models help visualise the likely threat of inundation using predictive data analytics. Such datasets as well as the tools/models to apply them strengthen disaster management as a whole.

Threshold. Not all rainfall episodes trigger floods and not all cyclonic winds cause structural damage. Knowing user-based threshold values is critical to evaluate impacts. Such triggering threshold information is derived from historical data in TNSMART and linked to real-time forecasts to visualize likely impacts (Figure 13).

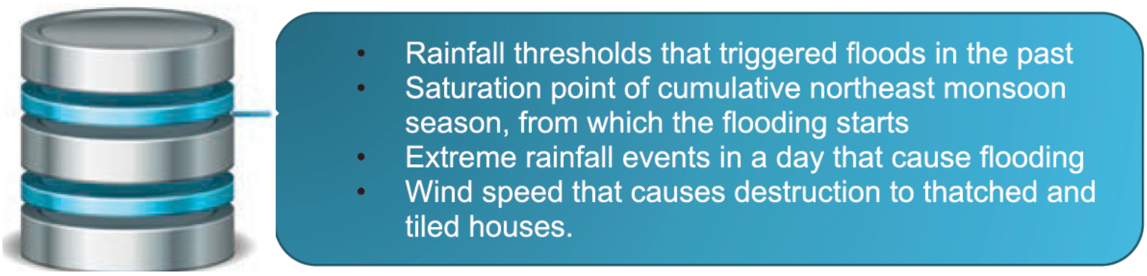

Figure 13 Threshold module

Hazard forecast. TNSMART has a hazard forecast module integrating various forecast products at different spatial scales from different global and regional centres, as well as with base geographical maps, to cater to the needs of different users.

Impact forecast. TNSMART uses the India Meteorological Department (IMD) rainfall forecast and assesses the season's rainfall and water level in reservoirs, to evaluate potential floods in vulnerable locations across Tamil Nadu. This module generates a list of vulnerable locations likely to be flooded in each district.

Advisories. TNSMART has a system to generate advisories for different users. The bulletin for operational users has magnitude of hazard and its possible impacts, likely affected villages and population, Dos and Don’ts and links to circulars on the disaster. The bulletin for the general public shows course of action to be taken and Dos and Don’ts at the community level.

Risk communication. TNSMART disseminates risk information to field-level operators and the public through emails, mobile app messages with alarms, social media, and websites. TNSMART has in-built functionalities to push messages through these platforms. TNSMART-based early warning alerts also use SMS, Disaster Warning Announcement System (DWAS), tower-based SMS broadcasting, fax, and telephone to communicate risks to vulnerable populations.

Mobile applications are widely used to: provide users with access to observed rainfall data, weather forecasts and likely flooding potential for identified vulnerable areas; communicate alerts; send distress messages from citizens; and receive action-taken reports on the alerts from field-level operators. These are shown in Figure 14 (TNSMART login page; flood-vulnerable locations and weather forecasts)

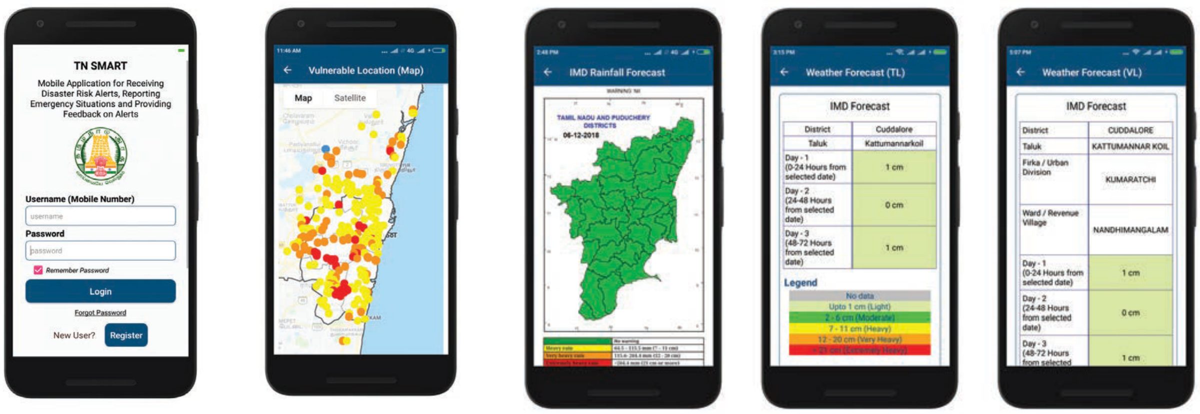

Figure 14 Use of smartphones in communication using mobile applications

4 Building a capacity development plan

4.1 Why impact-based forecasting?

All countries need to provide their population and economic sectors with actionable information that wherever possible identifies the timing and anticipated impacts of specific hazards.

Impact-based forecasting arises naturally from a focus on users’ needs. While the relevance of weather information to users is increasing, in most cases the information on the impact of the weather is more important in decision making by those at risk and those responsible for mitigating the risks.

Each year the impacts of severe hydro-meteorological events around the world cause casualties and significant economic losses. Why does all this happen in spite of the fact that many of these severe events have been well forecasted, with accurate warning information disseminated in a timely fashion by the responsible authority?

The answer to this lies in the gap between preparing forecasts and warnings of hydro-meteorological events and an understanding of their potential impacts, both by the authorities responsible for civil protection / emergency management and by the population.

To close this gap a holistic approach to observing, modelling, and predicting severe hydro-meteorological events, and the consequent cascade of hazards through to impacts, is needed. Tackling this problem requires a multi-disciplinary approach to access the best possible science to manage multi-hazard events and build community resilience to deliver the optimum services to those at risk.

To develop impact-based forecasting capability, it is necessary to transition science and technology advances into forecast operations, applying social science research to improve the communication and usefulness of information based on users' needs, expanding dissemination efforts to achieve responsiveness and resilience, and developing decision support systems. These are briefly described below.

Decision Support Systems

Decision Support Systems (DSS) combine various information such as hazard, vulnerability, and exposure data to provide the staff of NMHSs, DRM agencies and other stakeholders involved in impact-based forecasting with the information required to issue effective and actionable warnings. DSS promotes active involvement by weather forecasters in better understanding impacts of weather conditions on society. This knowledge makes the information and services NMHS, and DRM agencies provide more relevant to decision-makers.

Science and technology advances

Scientific and technological advances continue to result in improved accuracy of meteorological and hydrological predictions. However, a new focus on social science research is needed to ensure products and services convey risk and uncertainty in a manner that enables life-saving decision-making and triggers effective action.

Communications and outreach

Communicating preparedness messages and user education on how to apply forecast information to decision-making should focus on three objectives: i) be action-oriented, ii) provide consistent messaging of the expected risks and iii), reach out to vulnerable populations. Risk reduction and preparedness information for communities should be designed to guide the population on taking the necessary actions and not just creating awareness. Consistency in the message is critical for users to trust the information enough to act on it.

Information delivery

Information, such as lifesaving severe weather warnings, must be received by users in ways they expect, using technology with which they are familiar and accessible. An increasingly popular way to deliver warnings is via mobile devices. These warnings encourage users to seek additional information and safe shelter. Information delivered on mobile phones extend the reach of more traditional sources such as television and radio broadcasts, and websites.

4.2 Common approaches to IBF: qualitative versus quantitative approach

The Qualitative approach

This approach seeks to use knowledge and experience that exists in the forecast offices, emergency management agencies, local authorities etc. This approach relies on collaboration at all levels of government, private sector, volunteer organizations and academia, and is based on communication and user engagement. Forecasters need to work in partnership with users, especially other government agencies and stakeholders (emergency responders, mapping agencies, transport, public, etc.). Sharing of data (demographic, GIS, mapping, economic etc.) among different agencies and departments will be vital. Some of the data sharing will be anecdotal while some will be more rigorous. Understanding of impacts will come largely from experience, based on memory or previous events, traditional knowledge and use of historical records. The implication of this approach is that forecasters need to know and understand what the users do and how the weather effects their life and business. A plan for forecaster training in NMHSs to gradually move from hazard forecasting to impact forecasting is a key factor in the move to impact-based forecasts.

As a first step on the path to developing impact-based forecasting, most countries with developing NMHSs should be encouraged to start with the qualitative approach.

The quantitative approach

The quantitative approach in IBF follows the methods by which NWP weather models have been developed, in which vulnerability and exposure are modelled. This approach requires the application of advanced science and technology and assumes that knowledge of vulnerability and exposure can be developed or accessed, quantified, and merged with weather data.

One example is the vehicle overturning index (Figure 15) developed by the Met Office (UK) to model the likelihood of large trucks being overturned in strong winds on the UK motorway network. The end result of a substantial amount of background modelling and merging of data is a “simple” diagram of low, medium, and high-risk areas which provides guidance to police and road authorities to take mitigating actions such as closing the sections of the road to these vehicles during strong wind periods.

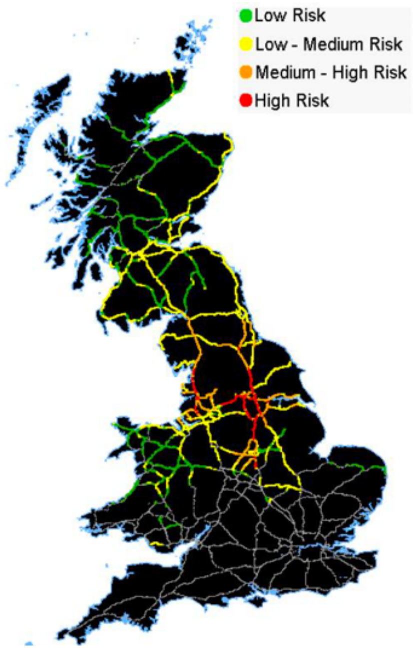

Figure 15 The vehicle overturning risk map
for in the UK

A second example is from the Pearl River Delta in China, which is one of the busiest shipping areas in the world. A sophisticated system to aid maritime safety and traffic management, requiring very significant IT resources and capability, was developed to integrate many different types, formats, and structures of data, including weather and ocean data. Such complex schemes are probably only possible in the technologically more advanced countries, yet they point to the challenges that will need to be taken on when embarking on a quantitative IBF approach. With advances in handling Big Data and the widespread use of probabilistic forecasting methods, this quantitative approach will most likely be adopted around the world in the long term.

4.3 Benefiting from experiences of those who are implementing IBF: Challenges

In implementing IBF, most countries face similar challenges, in varying degrees. These include accessing and learning to use more sophisticated forecasting techniques, increasing vulnerability of societies to a changing climate and severe weather, and reaching all the population at risk. Levels of challenges also depend on the level of development of the NMHS and partnering agencies, and available resources. Countries can learn from one another through open dialogue and sharing best practice.

The following is a summary of the most common challenges and suggested ways of overcoming them based on information shared by countries that are implementing IBF.

1. *Exposure and vulnerability data are often scarce or inaccurate. Impact data are often unavailable and incomplete*.
   - While data on exposure is relatively scarce, often there is more information on vulnerability (of infrastructure, services, and people) in different agencies, but dedicated and continuous effort is needed to access and collect these data.
   - Access and use of advances in technology – for example, the use of Light Detection and Ranging (LiDAR) and GIS is becoming more routine in many countries. There is a need to collaborate with other agencies in the country who have access to such technology and use their information on exposure and vulnerability. In addition to these sophisticated technologies, simpler tools such as surveys are in the reach of nearly all countries and sharing experience in good surveying techniques among agencies is valuable. Technologies such as machine learning and artificial intelligence are becoming increasingly accessible and when available within a country, they can be used to exploit imperfect data sets, such as those related to behavioural studies.
   - Use crowdsourcing to monitor impacts of hazards.
   - Use whatever exposure, vulnerability and impact data that can be accessed from various sources in the country to create impact databases.

2. *Forecasters are not committed to a changing forecasting paradigm and the move to produce forecasts and warnings based on impacts*.

   - Find a "champion" among the forecasting staff to lead efforts in IBF. Remember that the most experienced staff will not necessarily be committed to change, and sometimes it is the younger staff and new recruits who like to explore new paths and ways. Encourage NMHS staff to visit sites of hazardous events to see actual impacts on peoples' lives. Organize information-sharing sessions to introduce forecasters to the principles of impact-based forecasting and tell them they will not have to do it all by themselves (see point 3 below). Get the forecasters to move away from "this is how we have always done things" mindset.

3. *Coordination among different agencies.*

   - There needs to be a high-level direction and leadership from government – this may even be in the form of a legal mandate to deliver coordinated assessments, research, and advice on hazards to government.

- Arrange for information sharing sessions to demonstrate to various partner agencies that their role is very important, and their information is needed for better decision making to support the safety of lives and protection of the economy.
- Make these agencies valued partners in the process and get them to see what they should contribute to the process and why.
- Cooperate with academia in research and development on both physical and social sciences related to IBF.

4. *Lack of awareness and sufficient capacities at all levels (NMHS, DRM, Public)*.

- Capacity development in modern forecasting techniques and tools (e.g., Ensemble Prediction Systems (EPS) and products from global centres such as the Extreme Forecast Index (EFI)) should be started and remain an on-going process when moving to IBF. NMHSs should keep abreast of global and regional developments in strategies for future NWP. They should align their national strategies as far as possible with these developments, which would be the basis of a reliable forecasting system.
- Develop a verification programme at the NMHS and DRM agency and verify the actual impacts as well as meteorological forecasts. Collect, archive and share impact data routinely.

5. *Lack of integration with social sciences principles in NMHS. Lack of skill in communicating in different ways, inability to speak in a language that can be understood by users.*

- Use case studies and scenarios - what was done and what could have been done better if there was access to different information; how such information could have led to different actions and better outcomes.
- Explain uncertainty and probability to people: often they understand these concepts better than they are given credit for. It is not just disaster relief agencies who can benefit from reliable probability forecasts. In an original study, Webster et al. (2010)[15] showed that farmers in rural Bangladesh fully appreciate the value of probability forecasts for decisions on whether to move their livestock (often their principal assets) to higher ground. In Webster et al. (2010) it was shown quite conclusively that these farmers understood well the concept of probability, while many experts assume that probability concept is too complex for the average person to understand.
- Deliver the message using a variety of channels (social media, radio, television, web, email, SMS, telephone, etc.). This will ensure that a large percentage of the population will receive the information through one source or another.
- Keep in mind the reasons why people cannot, or do not, properly receive, interpret, or respond effectively to warnings. These can be physical (age, infirmity, physical or mental challenges), while others may be social or cultural (such as implicit bias in development of messaging, male versus female roles, the protection of property or livelihood, over-estimation of personal capability, poor judgement of risk)[16].
- Make sure the needs of people with disabilities are considered and ways of communicating the message to them has been included as part of the communication plan. This is fundamental to the design of the warning system because this group of population often requires much longer lead time in taking action based on warnings and therefore there is a need to understand how to warn them of low probability high impact hazards.

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[15] Webster, P.J., Jian, J., Hopson, T.M., Hoyos, C.D., Agudelo, P.A., Chang, H.-R., Curry, J.A., Grossman, R.L., Palmer, T.N. and Subbiah, A.R. (2010). Extended-range probabilistic forecasts of Ganges and Brahmaputra floods in Bangladesh. Bulletin of the American Meteorological Society, 91, 1493–1514.

[16] WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services (WMO-No.1150)-Part II-2021

- Conduct regular simple surveys to find out levels of public understanding of the messages and the required action.

6. *Lack of understanding and use of Ensemble Prediction System and digital data to produce better forecasts to move from deterministic to probabilistic forecasting and warnings*.

   - Models in major global and regional centres have been improved and tools are available from these centres to allow their use in forecasting at country level. Discussions on licencing the data and how to make them available to less developed NMHSs are ongoing.

7. *Inaccuracy of quantitative precipitation forecasts (QPF) to support reliable hazard warnings*

   - Learn how to use existing sufficiently high-resolution models, develop nowcasting capability and learn how to use ensemble probabilistic techniques to improve NMHSs capability for heavy rainfall prediction.

4.4 Building an understanding in implementing impact-based Forecasting: what works and what does not work

In order to build a common understanding of IBF among all actors who are involved in implementing it in a country, it is essential to address the issues listed below.

1. It is important to be very clear that the goal of impact-based forecasting is to make life simpler, safer, or easier for people and to explain it in a logical and stepwise manner.
2. Developing a common set of definitions of hazard, impact, and response tables, starts this process. This will overcome different understanding and interpretation of these terms.
3. This process of defining, understanding, and communicating brings the NMHSs and disaster managers together and helps resolve some of the challenges such as sharing the impact and vulnerability data held by disaster managers and other stakeholders.
4. Asking simple questions makes sure everyone (NMHS, disaster managers and stakeholders) understands the impact of a hazard in the same way, for example:
   a. Where is the storm going to happen? How large is the affected area? are there multiple locations affected by the same system?
   b. When is the storm going to happen? Is there time to assemble resources and evacuate people from flooded areas? This question shows the relevance of forecast lead time (The ***forecast lead time*** is the sum of the lead time and the time for decision-making and communication) and the importance of giving sufficient lead time (The ***lead time*** is the time between the moment a potential threat is identified and when it occurs, minus the decision and notification time) to DRM (and the population) to prepare for action.
   c. Multi-hazard events, for example a wind event at one location and a rainfall event at another may be different in severity. But both require response. Which one will have more serious impacts? How to gather resources to respond to both?
   d. Why is this storm a dangerous hazard? Is the ground too wet to absorb any more rain? What are the areas of vulnerability (houses on a slope or on a riverbank? Roads that may be cut off by rain or bridges that may get washed away in a swollen river?)
5. Verifying warnings will require setting up communication strategies so that there is a two-way communication channel set up between NMHSs and disaster managers.
6. Establishing clear standard operating procedures (SOP) will enable effective coordination among agencies. SOPs should clarify the roles of the NMHS and DRM. The role of NMHS should be emphasised as clear authority for the forecasting and warning of severe weather events.
7. Training the relevant personnel on how to effectively communicate risk, and uncertainty is essential.

8. Identifying the needs of the community, including those of disabled persons, to allow delivering consistent impact information (multiple languages, use of symbols, graphics, and icons, etc.) is key.
9. Optimizing graphical displays and dissemination capabilities of NMHS and DRM to process, interpret and display IBF information to support decision making is critical.
10. Developing a procedure for NMHS and DRM to collect and archive hazards and vulnerability information and tables is fundamental to success of an IBF system.
11. Developing an outreach campaign to familiarize the public with the NMHS and DRM's move towards impact-based forecasting is a vital ingredient of building trust in IBF.
12. Understanding different stakeholders' (e.g., first responders and disaster managers) major decisions and the kind of information they need to be able to make those decisions is key.
13. Providing consistent information at all levels of government (national, regional, and local levels) on the impacts of specific hazards is of significant importance.

4.5 Who are the actors in IBF production and delivery?

A successful impact-based forecasting service will require close operational cooperation among the agencies and individuals responsible for meteorology, hydrology, and disaster risk management, as well as first responders, NGOs, and voluntary organizations. Each of these have to fulfil a role in order to successfully advise the population on the impact of a particular hazard. A decision has to be made among these actors and agreement reached on how to lead and manage the process at a formal level. When this agreement has been reached, SOPs should be developed accordingly. Several levels of engagement are required in the countries in the *Caribbean* region when starting the impact-based forecasting approach. These are as follows:

4.5.1 NMHS Leadership

The commitment of the leadership of NMHSs under whose authority the system will be developed is a key in the success of an IBF system. The leadership has to understand and believe in the utility of the system since it requires committing human and financial resources of the organization. The leadership should keep abreast of developments in science and technology related to forecasting so as to apply the most appropriate solutions for the needs of the organization.

4.5.2 NMHS Management

Following the example of its leadership, the management of the NMHS should be equally engaged in a hands-on manner in the planning and implementation of an IBF system. Practical guidance in the organizational (re)arrangements for the most efficient implementation of the system should be provided at the management level. It is also the role of the management to initiate discussions with the partner agencies and organizations and to solicit their participation in the development of an IBF system. Formal approvals to form these partnerships should be given at the NMHS leadership level.

4.5.3 Meteorological forecasters at NMHS

The daily work of producing meteorological forecasts and warnings which will form the basic inputs into impact-based forecasts and warnings is the responsibility of the forecasters. This requires development of knowledge and skills to be able to use the up-to-date tools and techniques of forecasting and undertake training as required on topics such as EPS and probabilistic forecasting which form the basis of IBF. Preparing case studies for investigating the performance of the forecast models used at the NMHS and compiling a climatology of hazardous weather events should be part of the duties of forecasters. In the absence of dedicated staff (see PWS advisor below) the role of the forecaster will also include the delivery of public weather services.

The forecasters in collaboration with the DRM agency (National Disaster Management Organisation (NDMO) in the Caribbean region) should review and revise as needed the current warning protocols for hazards to ensure a consistent system common to all hazards. This will require identification of the types of hazards that lead to impacts and the creation of a hazard matrix defining primary, secondary, and tertiary hazards (Figure 20 and Table 4). This matrix will form a key component of a future multi hazard, impact-based early warning service.

4.5.4 Hydrological forecasters

In some countries meteorological and hydrological services are provided by a single organization, in which case they are co-located in the same facility. This should make the preparation of flood forecasts more efficient since the weather and flood forecaster can work closely on a given problem at the time of severe weather events which might lead to flooding. Where the functions of weather and flood forecasting are carried out by different organizations (where the Meteorological Service is responsible for flash flood forecasting and a hydrological organisation is responsible for forecasting other types of floods), it would be desirable that during severe weather, these forecasters should work closely together so that as the weather situation evolves, the flood forecaster can be guided in producing the required warnings. An example of this could be a flood forecasting centre where both organisations combine their expertise to find a better means of providing the most complete assessment of operational flood risk, from the developing weather conditions through to the actual flooding event itself. If such a facility cannot be provided, then at least a live communication channel should be established between the two organisations, whereby real-time updates on the evolving weather situation and continuous consultation among weather and flood forecasters can be made possible.

4.5.5 PWS advisor at the NMS (role of human in the process)

The qualitative process of translating hazard forecasts into impact-based forecasts in an understandable and jargon-free manner is the job of the Public Weather Service (PWS) advisor. The content will be based primarily on the experience of the forecasters, but the communication of the message is the responsibility of the PWS advisor. This process will lead to the development of risk matrices linking the severity of the impact with the likelihood of occurrence.

The PWS advisor fulfils the role of building a bridge between the science and technology-oriented forecaster and the DRM agency, media and other stakeholders who usually do not have a meteorological background but need to understand the message that is being conveyed by the forecaster. To discharge this role, the PWS advisor should have skill sets and knowledge in service delivery. These include relationship building with stakeholders such as the media and disaster management and generating trust; written and oral communication skills to clearly articulate often complex concepts of probability and uncertainty, presentation, and public speaking skills so as to project an authoritative figure; and user focus in order to be able to establish dialogue with and understand users' needs. Due to staffing or financial constraints it may not be possible for NMHSs to designate staff responsible for this specific role. In that case, NMHSs could designate one or two of their forecasting staff to develop the necessary skills to also act as PWS advisor(s) based on the skill sets listed above.

4.5.6 NDMO[17]

The relationship between NMHS and emergency/disaster management should be as close as possible, ideally with joint responsibility for developing and issuing impact-based warnings. It is essential that this relationship is based on trust and mutual understanding of respective roles and responsibilities of each partner agency. Developing standard operating procedures (SOP) with the NDMO will strengthen this relationship.

4.5.7 Vulnerability assessment experts in NDMO

It is necessary to determine the availability of vulnerability data. These include the vulnerability of infrastructure, services, and people. Detailed information on critical infrastructure and services should include roads, bridges, schools, hospitals and clinics, shelters, individual homes, transport, electricity supplies, water, and sanitation. As pointed out in Section 3.2, however, impact-based warning services should also focus on the social determinants of vulnerability – health, gender, income, education, psychological barriers, community behavior, and so on. The aim is to be as comprehensive as possible since these data help to determine more precisely the impact of specific hazards. Acquiring data on these factors goes far beyond the responsibility of NMHSs. This information may either exist at NDMOs or is accessible by them from other government agencies.

4.5.8 GIS Experts

The qualitative process of translating specific hazards into impacts was explained in Section 4.2. As all partners in the IBF process gain experience and become more confident in producing and disseminating this type of forecasts, the qualitative approach should be further refined through among others, using the more advanced vulnerability database. The next step would be acquiring and applying GIS expertise and experts in this field should participate in the process and produce impact-based forecast as a GIS layer to visualize the relationship between multiple hazards, vulnerabilities, and impacts. This expertise exists at the DRM agencies in most countries. If this is not the case, however, NDMO should be able to access it from other ministries or agencies in the country.

4.5.9 Social and behavioural scientists

Institutional strengthening and improving observing and forecasting systems are a necessary but insufficient condition to reduce impacts of hazards. It is necessary to understand why people do not move to safety when a warning is issued. Is it because they do not know of the danger, or they know it but choose to ignore it? Or perhaps is it because they do not trust the source of the information or do not understand the scientific language used in explaining the situation? Answering these questions requires the involvement of specialists in social and behavioural sciences who should be part of the partnership in impact-based forecasting. In most countries the NDMO, academic institutions such as university faculties, gender bureaus or government departments dealing with social issues may be good sources to provide this type of expertise.

4.5.10 NGOs and community level

Strengthening the communication of impacts to enhance last mile delivery through multiple media and channels such as the internet, mobile platforms/SMS, mass and social media, and

[17] While the generic term DRM agency has been used elsewhere in this document, the term "National Disaster Management Organisation" (NDMO) is used specifically in reference to the Caribbean region

community leaders, volunteers, the Red Cross, and the NGO networks is an important aspect of implementation of IBF. NMHSs would need to explore all of these channels and build relationships with whatever resources that exist in the country for helping them with the last mile delivery of the message of impact of hazards.

4.6 How do actors contribute to the process?

As has been explained in Section 4.5, each actor has a role in the sustainable implementation of IBF. The entire value chain, starting from observing and monitoring meteorological and hydrological events; applying forecasting tools and techniques to predict the future evolution of the hazard; determining the impacts of the hazards; disseminating and communicating the impact and helping to get the population out of harm's way, depends on the expertise and knowledge that the various actors bring to the process.

4.7 What skill sets are needed for each of the actors?

It is clear that while each actor has a specific skill set and responsibility, some knowledge by all actors of how the entire value chain works is of great benefit. This will allow a better appreciation of what is expected from each link of the value chain and how it will interact with and contribute to the entire IBF process. Initial training requirements would focus on i) weather forecaster training to improve the ability to interpret guidance products provided by global and regional centers; the use of existing ensemble prediction system products and tools to develop probabilistic forecasts and interpret them; and ii) hydrological forecaster training to apply weather forecasts in preparing flood forecasts, iii) NDMO training in co-developing the IBF and early warnings with weather and flood forecaster. Other areas of training will be on technologies such as GIS. Even if expertise in this area may exist in a particular institution, understanding among other actors of the application of GIS to IBF would be highly desirable. Forecasters and PWS advisors' training would also be required in developing and interpreting verification metrics, producing post-event analyses, and assessing the effectiveness of IBF together with NDMO. This technical training should be combined with soft skills, in communication and sustaining dialogue and outreach, to achieve the desired outcomes in changing behaviour and getting people out of harm's way.

4.8 How to build these skills?

Training of national trainers, in all aspects of the forecast process, is a first step to build a team of experts in the country. The trainers will implement the training, as a routine part of on-the-job training.

A matrix of capacity development for different actors, consisting of topics of training, length of training, frequency of training, delivery of training and cost of training is shown in Table2. This table should be further enhanced, with information about all actors involved, prior to the practical implementation of training activities. Details of training activities such as length, frequency, method of delivery and ultimately the cost will depend on the assessment of current skill sets of various actors and the level of end-users (recipient of services) requitements.

Table 2 Capacity development matrix of all actors involved in IBF

Actors	Topic of Training	Training Length	Training Frequency	Training Delivery	Training Cost

NMHS Leadership	• Competencies in IBF principles and Practices				
NMHS Management	• Competencies in IBF Principles and Practices • partnership building				
NMHS Forecasters	• use and interpretation of global and regional forecast products • interpretation of the new forecasts with probabilistic information • verification of forecasts • understanding the principles and practices of impact-based forecasting and warning services (cascading hazards, risks, early action and response) • developing a common set of hazard, risk, early action and response matrices in collaboration with other actors				
Hydrological Forecasters	• principles and practices of impact-based forecasting and warning services (cascading hazards, risks, early action and response) • building/interpreting /understanding (as applicable and relevant) hydrological models for flood forecasting • developing a common set of hazard, risk, early action and response matrices in collaboration with other actors				
NDMO and first responders	• principles and practices of impact-based forecasting and				

	warning services (cascading hazards, risks, early action and response) • developing a common set of hazard, risk, early action and response matrices in collaboration with other actors • Co-developing impact-based forecasts with weather and flood forecasters • Interpreting vulnerability information and its integration into impact-based forecasts • Community engagement • Communication skills				
PWS Advisors at NMHS	• principles and practices of impact-based forecasting and warning services (cascading hazards, risks, early action and response) • Developing partnerships, especially with NDMO • stakeholder and Community engagement to develop a clear understanding of user requirements and capacities to respond to warnings • interpreting and clearly communicating the hazard, risk, early action and response matrices to stakeholders • outreach activities for general public				
NGOs and Volunteers	• principles and practices of impact-based forecasting and warning services				

	(cascading hazards, risks, early action and response) • Community engagement • Communication skills				
Community Leaders	• Basic principles of IBF • communication skills to advise and work with members of the community				
Social Scientists	• principles and practices of impact-based forecasting and warning services (cascading hazards, risks, early action and response) • communication skills to work with members of the community				
GIS Experts	• principles and practices of impact-based forecasting and warning services (cascading hazards, risks, early action and response) • application of GIS to developing IBF				
Vulnerability Assessment Experts	• principles and practices of impact-based forecasting and warning services (cascading hazards, risks, early action and response) • understanding the role of vulnerability data in developing IBF • communication skills to work with members of the community				
User Sectors (transport authorities, water resources managers, municipal	• general principles and practices of impact-based forecasting and warning services (cascading hazards, risks, early action and response)				

authorities, domestic and industrial energy suppliers, health sector, the public, etc.).	• specific training on IBF for different users based on their requirements (role of PWS advisor)				

5 Assessment of the current capacities of the CARICOM

For the purposes of this IBF implementation plan, developed through the World Bank CREWS Caribbean project in support of the Regional MHEWS Roadmap prepared under the project, the Caribbean region is considered to comprise the 20 member states and associate states and territories of the Caribbean Community (CARICOM)[18].

In order to develop and elaborate the steps in this implementation plan, an assessment was made of the current meteorological, NDMO, EWS and IBF capacities and operational situation of the CARICOM countries with the aid of a regional meeting and a regional matrix.

The areas where information was gathered include:

- National MHEWS policies, including any legal frameworks for disaster risk management and emergency response
- National roadmaps based on CDEMA model policy on MHEWS
- Organizational aspects of emergency preparedness and response; obstacles including nstitutional barriers
- Identification of roles and responsibilities of various institutions (meteorology, hydrology, DRM) in the EWS
- Ongoing collaboration among various institutions and organisations related to meteorology, hydrology, DRM
- Existing early warning systems
- Forecast and monitoring technologies, warning production and dissemination capabilities and responsibilities, products and services delivered by the NMHSs
- Process for issuing advisories or warnings, type of information available and used, and the type of information that is needed but lacking
- Disaster response plans and practices
- Degree of success of the existing early warning systems
- The current status in understanding and implementation of IBF
- The underlying causes/obstacles that prevent the countries from implementing IBF
- Tools, commitment level and knowledge needed to overcome the obstacles, to initiate IBF and to move the countries to more advanced stages of implementation
- Initiatives being implemented towards IBF

Based on the outcome of this baseline assessment, a criterion was established to form groupings of countries centred around each country's capacity (e.g., skills, competencies and available tools), dependencies (i.e., receiving/providing forecasts from another CARICOM state), current projects that are IBF related (e.g., WCRNs, storm surge and Tsunami ready),

[18] CARICOM Member States: Antigua and Barbuda, Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, Saint Lucia, St Kitts and Nevis, St Vincent and the Grenadines, Suriname, Trinidad and Tobago. CARICOM associated states and territories: Anguilla, Bermuda, British Virgin Islands, Cayman Islands, Turks and Caicos Islands.

relationship between NMHSs and NDMOs, and the strategic plans available for review (Table 3).

In order to achieve the purpose of this implementation plan (Section 1), in parallel with and based on the steps elaborated in the plan, a series of IBF training webinars were developed for the countries based on the established grouping. The webinars include formal presentations and teaching, group discussions, and case studies.

Table 3. country groupings based on the selection criteria

Group	Country	Forecast & dissemination capabilities & responsibilities	IBF initiatives	Current related projects	Disaster Policies & plans	Relationships NMHS&NDMO	DRM legal framework
1	Antigua and Barbuda	Operational NMS Provider of forecasts & warnings for other CARICOM States Back up arrangements	No	No	Yes	Yes The National Office of Disaster Services has legal cover	Yes
	Montserrat	Forecast & warnings from another CARICOM State	No. Any IBF initiatives will have to include ABMS	No	Yes	The NDO gets the forecasts and warning from (ABMS)	Yes
	Saint Kitts and Nevis	Forecast & warnings from another CARICOM State	No	No	Yes	Yes	Yes
2	Guyana	Operational NMS	No	No	Yes	Yes	No
	Suriname	Operational NMS					
3	Barbados	Operational NMS. Provider of forecasts & warnings for other CARICOM States	WRN-pilot phase	Expansion of the 3DPAWS Network	Yes	Yes	Yes
	Dominica	Forecast & warnings from another CARICOM State	WRN	DVRP UNDP	Yes	Barbados Meteorological Service	In process
	St. Vincent & the Grenadines	Forecast & warnings from another CARICOM State	WRN	No	Yes	Yes	Yes
	Saint Lucia	Operational NMS Back up arrangements	WRN	Yes	Yes	Yes	Yes
4	Bahamas	Provider of forecasts & warnings for one other CARICOM State Back up arrangements	WRN				Yes

	Jamaica	Operational NMS	WRN	Yes. Building Resilience Through Climate Adaptation technologies (BReTCAT	Yes	Yes	Yes
	Belize	Operational NMS Back up arrangements	No	No	Yes	Yes	Yes
	Haiti	Operational NMS			Yes		Yes
5	Trinidad & Tobago	Operational NMS. Provider of tropical cyclone forecasts & warnings for one other CARICOM State Back up arrangements	Yes (in part) CAP has been implemented	Nil	Yes	Yes	In progress at the moment
	Grenada	Operational NMS / forecast & warnings from another CARICOM State	WRN	No	Yes	Yes	Legislation is being finalized

6 Steps in developing capacity of NMHSs, disaster management staff, partners, and users for producing and using impact-based forecasts and warnings

Impact-based forecast and warning production relies on a wide range of technical, human and financial resources and capabilities.

Developing a capacity building plan and its implementation is essential for the success of impact-based forecasting and warning services. An essential part of developing such capacity should be relationship building and developing skills in collaboration and communication with officials from other organizations. Building trust among all involved is a key to ensure that all participating agencies and individuals realize the crucial role that each play towards maximizing public safety in the face of a changing climate and severe events.

Sharing of information and data is a specific aspect of such relationship building. In the case of many countries special authorization needs to be granted by higher levels of government in order for different organizations to share their data. While the first goal of capacity development is to focus on basic principles and common issues in approaching impact-based forecast and warning services, in-country training should be conducted for all members of the operational team, which at a minimum would include designated personnel from the NMHS and NDMO. In an ideal situation, the NDMO specialists and hydrological specialists from the NHS (if this exists) or water resource management agency would be temporarily assigned to work within the forecast office of the NMHS. These specialists would have responsibility for developing the impact-based forecasts and warnings, based on the meteorological and hydrological information and forecasts. If this is not possible, alternative approaches should be explored to determine other arrangements, such as mirrored displays of real-time data, imagery and information from the forecast office in the NDMO operations centre. The initial training would focus on the qualitative translation of weather forecasts to impact-based forecasts and warnings.

In-country training should be viewed as a continuous process, in which personnel from all relevant agencies are involved in a long-term program to improve competencies, confidence, and sustain their skills. Twinning arrangements, peer learning study tours and familiarization visits should also be considered and organized, if possible, as additional resources to expose senior management and practitioners to best practices in other countries, following the initial in-country training.

In the case of the NMHS, priorities for technical training should focus on modern forecasting methods and the application of technologies that are fit for purpose for the level of the particular NMHS' capacity. For example, in the absence of radar which would allow more reliable and accurate forecast of rainfall due to convection, other technologies or techniques such as the use of satellite imagery could be employed by the forecasters to help them with this kind of prediction. Twinning with one or more advanced NMHSs, which have already developed impact-based forecast and warning services, will enable the NMS to focus more attention on translation of meteorological and hydrological information into impact-based forecasts and warnings. The pairing arrangement would also provide an opportunity for agreeing on operational backup for the forecasters, enabling them to receive guidance on complex weather situations.

As pointed out in Section 4.2, there are two approaches to impact-based forecasting. In order of progressing complexity, these are qualitative and quantitative approaches. It is recommended that in the first instance, the focus should be on **qualitative** impact-based forecasts. These would be created by translating meteorological and hydrological hazards into actionable information that is understood by the public as well as institutions and officials responsible for disaster management and civil protection. The second approach, which is technically more complex, would bring together hazard forecasts with information on vulnerability and exposure, to provide more specific **quantitative** impact-based forecasts.

The activities which should be considered as part of a capacity building programme in this implementation plan are described in the following steps.

6.1 Step 1: Operational Partnerships for joint development of information and services

Developing a successful impact-based forecasting service requires partnerships and collaboration. Focusing on one hazard and one sector when beginning, will allow the impact-based forecasting process to develop without the added difficulties of tackling multi- hazards and many different user requirements. NMHSs and partner organisations should work with users to determine which hazard to prioritise.

Hazards may occur on different timescales, such as a seasonal timescale (wet season, extended summer heat wave), a monthly timescale (severe wet period, cold or hot period), a weekly timescale (cyclones), a daily timescale (thunderstorm) or a short notice/nowcast timescale (convective storm producing hail or flash flooding). Regardless, the methodology for producing impact-based forecasting is the same. Users' greatest concerns may be linked to multi- hazard situations, such as storms. In these cases, breaking multi-hazards down into individual hazards (Section 6.4, Step 4) makes the task more manageable. For example, where wind hazards are one element of concern during storms, impact-based forecasting specifically for wind hazards can enable mitigation of impacts of strong winds.

All impact-based forecasts and warnings should contain similar types of information, including:

- Time and date of expected impacts: this may not be the same as time of hazard occurrence e.g. flood events have a delay between the beginning of the rainfall and impact
- Location of impacts: may also be different from where the hazard occurs
- Severity and likelihood of impacts
- Types of impact: who and what may be impacted and how
- Hazard information: some users still require information relating to the type and magnitude of hazard
- Advice and guidance on what actions to take (when the service is for an institution, early actions are already predefined in advance and do not need to be provided in the warning), but advisory action should be provided to the public.

Partner organisations can help identify the impacts that are of most concern to various users, assess user requirements, and understand the hazards that drive those impacts. A strong collaborative approach brings together the producers of weather, climate, hydrological and risk information with those who use the information to make decisions. Working with partners to co–design, deliver and analyse the outcomes is an important aspect of these partnerships. Through such a co–creation process, partners contribute their expertise and insights– strengthening the learning design and process. Partners are also critical in communicating impact-based forecasts and warnings. Some partner organisations will have responsibilities to prepare for and respond to weather and climate events. These actions most likely include providing advice to vulnerable communities on what to do in an extreme weather or climate event. Combining such advice with impact-based forecasts and warnings can provide a seamless forecast and advice service to users.

When developing partnerships and collaborations, challenges to successful implementation are common. A few of those potential challenges with new partners or collaborators are listed below.

- Lack of knowledge about what impact-based forecasting is
- Lack of recognition of the added value of impact-based forecasting for early action
- Lack of incentives (including financial resources) to move towards impact-based forecasting
- Limited technical capacity of forecast providers to develop impact-based forecasting services
- Different administrative procedures of potential partners (for example government agencies) operating under different ministries
- Lack of clarity on whose mandate it is to develop and issue impact-based forecasts

As a minimum, close operational cooperation between three key agencies responsible for meteorology, hydrology and disaster management is necessary. This would include using operational forecasting capabilities of the NMS, joint development of flood forecasting, and joint operations combining the expertise of meteorologists, hydrologists, and disaster managers. The NDMO's role in most countries will be to help evaluate vulnerabilities, potential impact, and mitigation actions necessary to counter impacts. Depending on national public policies, the NDMO could be in the position to lead the impact-based warnings development and dissemination process, even if these are initiated and supported by the NMHS. The capacity development programme should clearly describe how to secure the commitment of the signatory agencies to work closely together, enabling the sharing of data, information and expertise.

The partnership should also include other organizations as necessary. The details should be developed during initial definition of the partnership. The partners should have access to technologies and training (Section 4.8) to enable them to effectively contribute to the process. Partnerships can be codified through formal documents such as Memoranda of Understanding (MoUs), service level agreements, and standard operating procedures between agencies. The implementation of a joint operations centre should be considered. The partnership would also benefit from the inclusion of media, NGOs and others responsible for direct interaction with communities

An example of such partnerships is shown in Figure 16. This figure shows the key organizations that play a leading role in the Natural Hazards Partnership (NHP) which was created in the United Kingdom to improve the coherence and quality of hazard management across government, and the planning, preparation, warning and response to natural hazards.

Figure 16 UK Natural Hazards Partnership

6.2 Step 2: Community engagement

In designing and implementing impact-based forecast and warning services (IBFWS), engaging the public and communities at the earliest stage is key.

The user-centric, inclusive approach to IBFWS considers the human dimensions of countries' hazard vulnerabilities. It is concerned with individuals, communities and enterprises that may be highly vulnerable and exposed to the impact of a hazard or group of hazards. Engagement with communities to understand who is at risk involves many different entities including social and behavioural scientists, disaster managers, non-governmental organizations, civil and structural engineers, risk finance and risk transfer specialists, and, importantly, those at risk. The latter includes people with a range of vulnerabilities, including poverty, disability, gender, ethnicity, religion, low literacy, lack of knowledge and experience, geographic and social isolation, the ability to transfer risk and trust, among many other factors.

Having more accurate, timely and highly refined information that can be accessed and transmitted quickly and efficiently via a range of channels will certainly contribute to a more effective early warning system, but it does not define one. Over time there has been much discussion around what constitutes and defines a 'warning'. There is now general agreement that a 'warning' service does much more than deliver a message that provides event-specific detail, which is certainly an essential element of the service. However, it must also contextualise the information so that it 'nudges' the receiver towards appropriate behaviour and enables a willingness and ability to take protective action. The views of communities should be sought to identify the kinds of messages that will encourage the appropriate reaction to warnings.

A warning message that prompts and enables actions that effectively minimise loss of life, property and societal assets, of both tangible and intangible value, must include the following elements:

a) the most scientifically accurate and timely hazard-related information that is possible to source
b) relevant detail of potential impact and consequence based on informed risk-assessments
c) information which is communicated consistently in a range of formats via a range of communication channels that are appropriate for the target recipient population
d) information which is being clearly understood
e) information in the warning that is consistent with hazard awareness education and personal (or community) experience and expectations (as recipients will seek to confirm the detail)
f) detail which is contextually relevant – and this should be based on a deep understanding of the needs, capacities and vulnerabilities of the recipient communities
g) the source and detail of the information that are trusted (as this will underpin a willingness to take appropriate recommended defensive actions)
h) systems and processes that are in place to enable actions for achieving good outcomes.

Effective warnings are therefore the outcome of a process that starts with scientifically based information and ends with effective individual, community or sectoral action. This user-centric process requires networked expert input and contribution from a range of authorities – more extensive than just the hazard agencies and disaster management–working in partnership. It also requires work that is focussed on the 'users' of warnings and across a wider time frame than 'imminent threat' and activation of the emergency operation centre.

User-centric impact-based forecasts and warnings are dependent on the service being developed, with a clear and deep understanding of the social and demographic profile of the user community–to the finest level of detail and scale possible; an accurate hazard (risk) assessment over a geographically defined area; and a mapped and clearly described evaluation of the exposure and vulnerability of the elements at risk–including critical and physical infrastructure and both engineered and societal mitigation strategies[19].

This forms the basis of an impact-based warning system, that can be designed to be inclusive, so as to ensure accessibility of information and services that are appropriate to identified and understood needs, capacities and capabilities of all members in any recipient community and across a range of abilities.

Some training that includes operational agencies, community representatives and responders, will be required to make effective use of the forecasts and warnings.

6.3 Step 3: Establishing a common framework for warning services

Creation and use of a common shared platform for multiple agencies to work together collaboratively is the backbone of an IBFWS.

As NMHSs develop their forecasting capabilities, assuming their access to high quality digital forecast products from the global centres, the forecast offices will need to decide how to display basic meteorological warning information. This will be a significant step for NMHSs to move from providing text-based warnings to visual displays.

The MeteoAlarm Portal

Mapping the distribution of hazards and impacts geographically is the preferred approach, using administrative boundaries as polygons or grid cells, to present the location of the hazard and impact. Each of these polygons or grid cells may have its own granular structure depicting a much finer mesh and facilitating more detailed warning information. The advantage of mapping administrative boundaries is the presence of public officials in each of the "grid cells", who have a responsibility for public safety.

Colours – green, yellow, orange and red – are used to represent the severity of the warning, while symbols for each of the meteorological hazards – wind, rain, lightning/thunderstorms, heat and snow/ice are displayed to show the type of hazard.

Meteoalarm (Figure 17), led by the Austrian National Meteorological Service (ZAMG) is an outstanding exemplar of a common framework for warning services in hydrometeorology. It has extended the visualization of such warnings to most of Europe using consistent colours to represent the severity of the hazard, together with employing a standard set of symbols for each of the meteorological hazards – wind, rain lightning/thunderstorms, heat and snow/ice which are displayed to show the type of hazard[20].

Ultimately the colour coding should be related to the impact of the hazard rather than the hazard itself, reflecting the shift in emphasis to actionable information for those at risk. The level red is therefore primarily defined by the advice: "follow the order of authorities under all circumstances and be prepared for extraordinary measures" and in this way it is result-orientated, instead of being focused on meteorology.

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[19] L. Anderson Berry: Report in support of the World Bank Climate Resilience Multi-Phase Programmatic Approach Project. (CRes MPA, P160005)-2020

[20] David. P. Rogers et al. COVID-19 and lessons from multi-hazard early warning systems. Journal of Advances in Science and Research (2020)

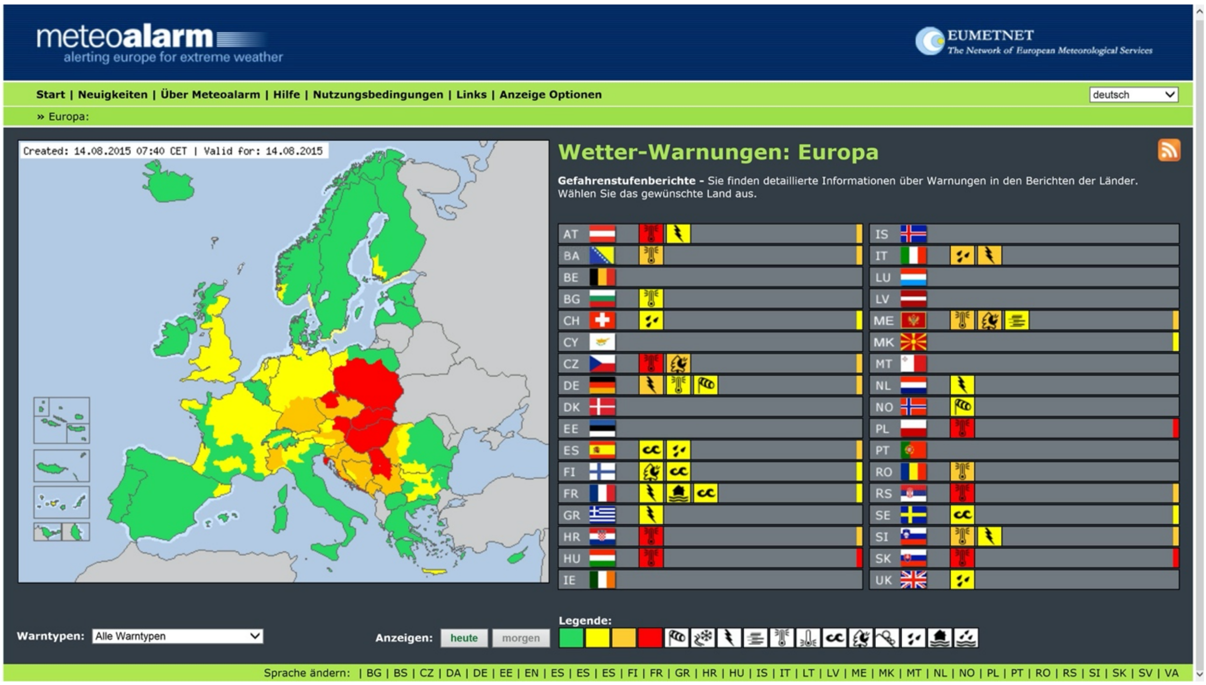


Figure 17 Example of the graphical output from the MeteoAlarm portal. The color coding is consistent across all participating European countries

.

Figure 18 shows the detailed warning system for Germany, which could be applied in any country.

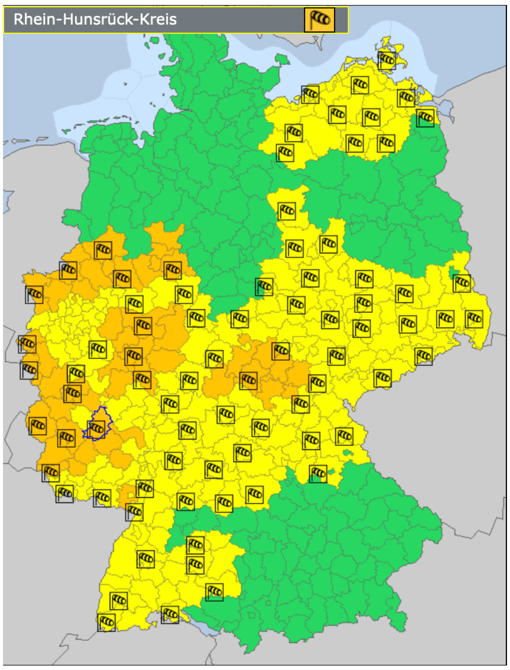


Figure 18 Example of the German Weather Service (Deutscher Wetterdienst) Warnings displayed using MeteoAlarm

The Caribbean Dewetra Platform

The Caribbean Dewetra Platform is a spatio-temporal, decision making, data fusion platform capable of seamlessly integrating evolving hazard data, socio-economic and vulnerability information in support of improved decision making within the disaster management community. Ground and space-based near real-time hydrometeorological observations, in addition to numerical weather prediction outputs, are presented in an online geospatial environment accessible by multiple users. Country specific information such as digital elevation models, slope models, watershed extents, hazard maps, population demographics and critical infrastructure can be merged with hazard data, to rapidly identify potentially exposed assets and support impact-based forecasting. The ability to crowd-source reported impacts, through the use of smart device applications, provides a useful workflow within the platform for impact verification, managing response actions and damage assessments.

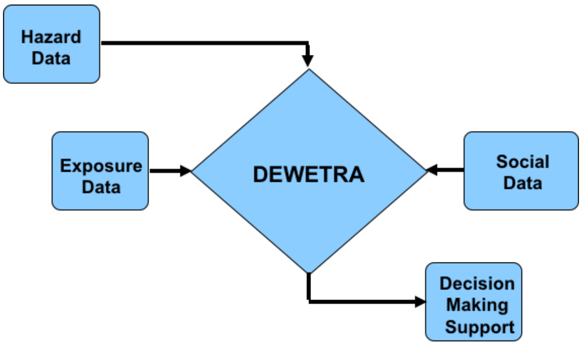


Figure 19. The Caribbean Dewetra Platform: A data fusion and multi-hazard impact forecasting decision making tool.

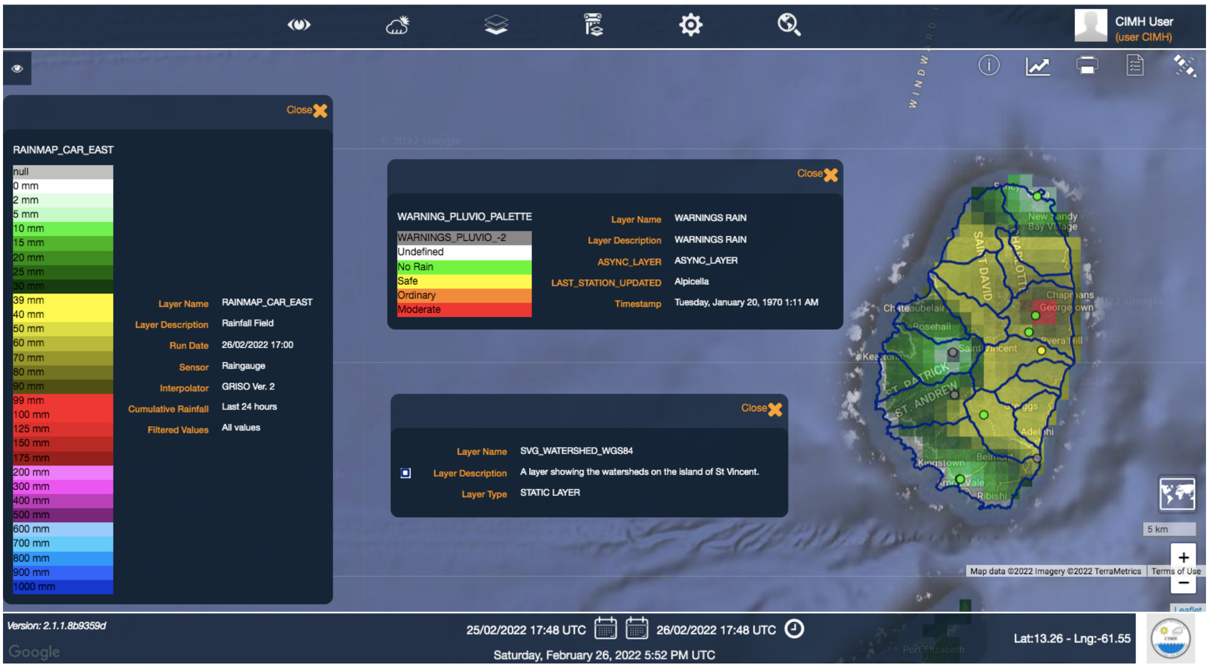


Figure 20. Near real-time rainfall spatially averaged across watersheds in St. Vincent as viewed on Dewetra Platform

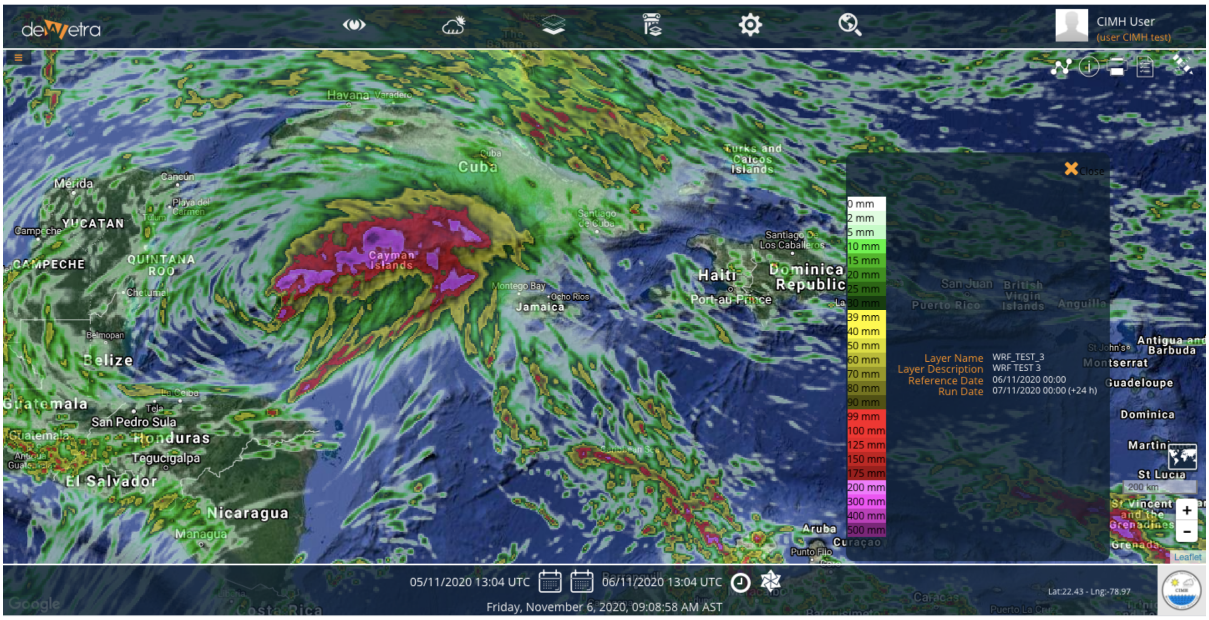


Figure 21. A 24-hour rainfall accumulation forecast for Hurricane Eta shown on Dewetra Platform

6.4 Step 4: Developing the Hazard matrix

The implementation plan includes the identification of the types of hazards and the creation of a cascading hazard matrix defining primary, secondary and tertiary hazards. This matrix will form a key component of a future multi hazard, impact-based early warning service.

Thus, the identification of weather-related events impacting one or more countries in the region, and the primary, secondary and tertiary hazards (Table 4) is required. The primary hazards are caused directly by the event and cannot be mitigated to any significant extent (e.g., rain will fall). The secondary hazards are related to the primary hazard and can often be partially mitigated (e.g., structural works can reduce the possibility of a flood in an urban area). The tertiary hazards, which are generally non-meteorological or hydrological, are caused by the primary and secondary phenomena or may be a consequence of human failure. The latter has the greatest scope for mitigation by either structural measures to reduce vulnerability or exposure or both. An example of cascading hazards and their impact is a warning of illness (risk of impact), which could occur in the population vulnerable and exposed to an infectious disease (tertiary hazard) caused by contaminated floodwater (secondary hazard) resulting from a flood produced by rains (primary hazard) as a result of a tropical cyclone (event). Based on this information, sector-by-sector hazard matrices can be developed.

It is essential to distinguish between an **event** (such as a tropical cyclone) and a **hazard** because a single event may include multiple hazards. Tropical cyclone events include a number of different hazards; it is the high wind, rainfall, landslides, soil erosion, lightening, flash floods, riverine floods and storm surge within the cyclone that cause the damage (Figure 20). The intensity of these hazards is highly variable in time and space requiring precise location-specific forecasts. The use of the various scales to estimate tropical cyclone intensity is at best only indicative of the strength of the winds, it does not say anything about the specific impact of the meteorological and hydrological hazards. This can be misleading.

Hurricane Sandy (2012)[21] illustrates the problem: in this case, responders and communities lowered their guard interpreting the meteorological downgrading of the storm from a hurricane to an extratropical cyclone by the National Weather Service as a weakening of the intensity of the overall system. In fact, the winds remained strong resulting in extensive damage that might have been averted had the communities and responders remained more vigilant.

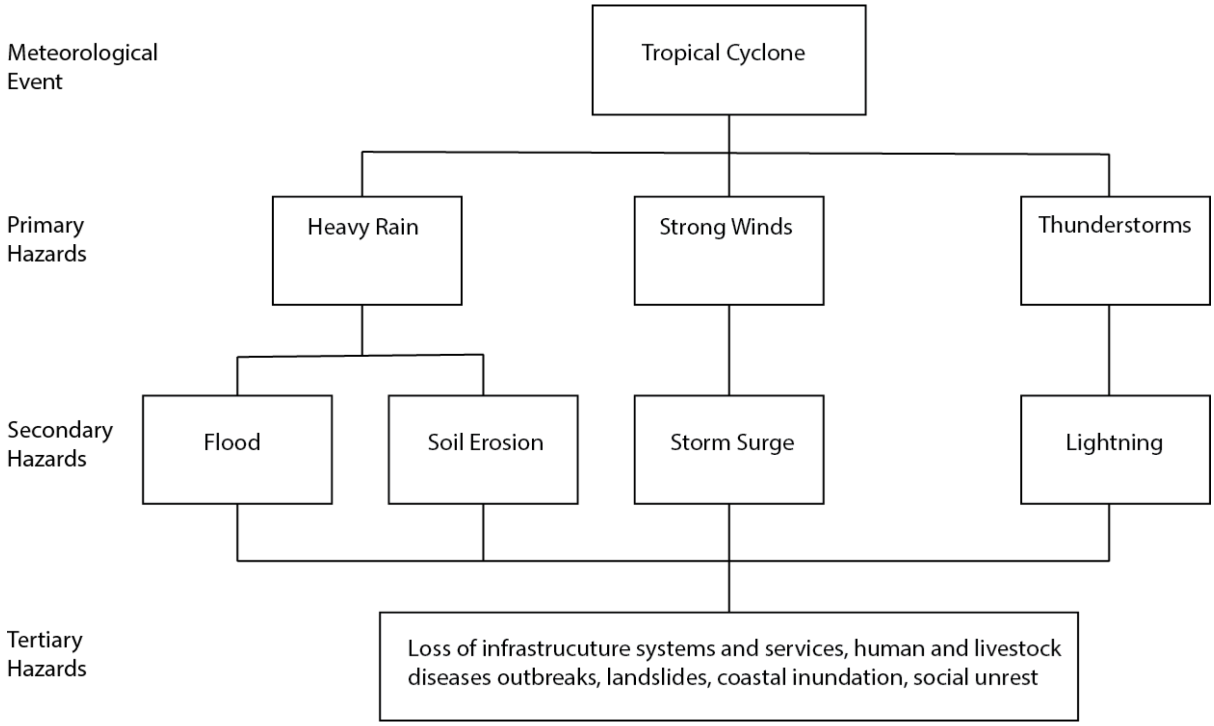


Figure 22 Schematic of a hazard matrix hierarchy illustrating the cascading nature of hazards

Table 4 Examples of multiple hazards resulting from a meteorological event

Event	Primary hazard	Secondary hazard	Tertiary hazard	High impacts
Hurricane	• Strong winds • Tornados • Lightning • Heavy rainfall	• Riverine flooding • Urban/Surface water flooding • Flash flooding • Storm surge • Landslides • Water level rise in reservoirs • Riverbank erosion	• Damage to dams and appurtenant structures, embankments, irrigation and drainage facilities, pumping facilities • Submerged paddy fields • Migration	• Loss of property and livelihoods, resulting in increased poverty and homelessness • Excess number of deaths and injuries due to the event and subsequent disease outbreaks

[21] Hurricane Sandy was the deadliest, the most destructive, and the strongest hurricane of the 2012 Atlantic hurricane season. The storm inflicted nearly $70 billion in damage and killed over 230 people across eight countries from the Caribbean to Canada.

		• Mudslides	• Loss of infrastructure systems and services (shelter, transportation, schools, hospitals, energy supply, communication) • Waterborne diseases • Environmental degradation • High sediment transport into reservoirs	• Loss of agricultural land and potable water resources • Widespread food and water insecurity, especially in the poorest communities, increasing morbidity • Risk of theft of property resulting in people not taking shelter • Severe disruption to transportation networks • Widespread population displacement • Psycho-social impact • Economic instability • Civil unrest and political instability
Drought	• High temperature • Heat wave • Reduced rainfall amount	• Water scarcity • Low river flow • Forest fire • Crop damage	• High evaporation loss in reservoirs • Shortage of water storage in reservoirs • Salt intrusion into the soil • Food shortage • Energy shortage • Air pollution/haze • Smog/dust • Sand dunes formation	• Widespread food and water insecurity, especially in the poorest communities, increasing morbidity • Widespread population displacement • Economic instability • Civil unrest and political instability
Earthquake	• Shaking of the ground (resulting in infrastructure destruction and damage) • Shifting Geological Formation	• Landslides • Tsunami • Urban fires caused by damage to gas and electrical supplies	• Damage in Dams and supporting structures, embankments, irrigation and drainage facilities, Pumping Facilities, • Loss of Infrastructure System and Services (shelter,	• Widespread population displacement • Widespread devastation, impacting especially the poorest communities,

			transportation, schools, hospitals, energy supply, communication) • Coastal Flood • Changes in Ground water formation	• increasing morbidity and psychological problems

Climatology can be used to generate return periods, commonly used to explain the probability of an extreme event of a certain magnitude happening in a given year. A common misconception is that a weather or climate event with a 5-year return period will happen once every five years. The correct meaning of a 5-year event is a 20% probability - taking heavy rainfall as example, this would refer to rainfall amount with a 20% probability of being exceeded in any given year. Five-year events can occur in the same year, consecutive years, or several years apart.

6.5 Step 5: Vulnerability and Exposure Assessments

The definition of vulnerability was given in Section 3.5.1. In this section vulnerability and exposure assessments are being considered, but it is important that as a first step, all partners in the IBFWS process agree on what is meant by vulnerability and exposure. The image in Figure 23 illustrates this well[22].

Figure 23. A ship and a lighthouse in stormy seas – vulnerability and exposure

In the image, the ship and lighthouse are both exposed to the stormy seas and severe weather hazard, but only the ship is vulnerable to the impact of the storm (the risk of sinking or wind and wave damage). As pointed out in Section 3.5.1, exposure is a necessary, but not sufficient factor of risk. It is possible to be exposed but not vulnerable.

Three important components of vulnerability and exposure should be considered as described below.

[22] David. P. Rogers (2021)-WB presentation to the South Asia Hydromet Forum

Human dimensions

- Poverty, physical and mental disability, age (old and very young), gender, culture, ethnic and religious diversity, geographic isolation, homelessness, level of education, understanding and knowledge, ability to transfer risk, trust, etc.

Infrastructure and sectoral interdependencies

- Buildings, bridges, shelters, financial systems, health systems, transport systems, energy, water, food, ICT infrastructure, etc.

Services

- Emergency services, health services, utility services, availability of equipment, medicines, etc.

It is necessary to determine the availability of vulnerability data, access it analyze it and know how to use it. A specialist should be part of the partnership to carry out this task, although it would be a good idea for other actors to also learn about vulnerability assessment. Vulnerability data about infrastructure and services relates to roads, ports, airports, bridges, schools, hospitals and clinics, shelters, homes, prisons and detention centres, electricity supplies, water and sanitation supplies, local governance, and demographic information. This information is normally available in one or more government departments (planning, public works, survey, census, etc.). Analyzing vulnerability data can also identify the potential for one hazard to create another. For example, high winds and heavy rain that causes flooding could create a hazard of electrocution if overhead power lines are blown down in flooded areas.

The human dimensions of vulnerability – particularly those dimensions which marginalize people – are often overlooked or underplayed. Within any society there are individuals, groups or communities that typically tend to be marginalised, either overtly or in a subtle way. This often includes women; ethnic and religious minorities; the very old and very young; and those that are geographically isolated with social disadvantage arising from poverty, internal migration, and homelessness. These individuals, groups and communities suffer social disadvantage by degree, often live on the margins of society, and in times of emergency and disaster they will be among the most vulnerable.

Involving social and behavioural scientists, disaster managers, nongovernmental organizations, civil and structural engineers, risk finance and risk transfer specialists, and engaging the population at risk to gather data, as an important layer of information within decision support systems, is an important factor in recognizing and taking into consideration the human dimension which makes early warning systems and services people-centred. In this regard, particular attention should be paid to the protection of personal data.

Training on various tools and their applications in gathering and analysing vulnerability data should be provided as part of any IBFWS capacity building plan, although as a first step the simplest form of vulnerability information can be based on expert knowledge, which can be used to develop qualitative statements about impacts.

Understanding sectorial interdependencies (Table 5) is also necessary to determine vulnerabilities, and therefore interdependencies of sectors on each other are important in developing appropriately tailored impact-based forecasts and warnings. Addressing these vulnerabilities is a way to increase resilience and reduce the risk of disaster stemming from a failure to cope adequately with the primary and secondary hazards. Not considering these, may result in the under-performance of many warning services. Figure 22 shows a summary of these sectoral interdependencies.

Table 5 Examples of sectorial interdependencies for 7 sectors

Sector	Sector dependencies on Infrastructure	Dependencies of other sectors
Food	• Water for irrigation • Transport infrastructure for agricultural activities and food supply • Energy for storage and agricultural activities	• Population is dependent on food supply
Energy	• Water for cooling in power stations, fuel refining and energy production • Transport for fuel supply and workforce • ICT for control and management systems of electricity	• Transport is dependent on energy • Food production is dependent on energy • Water is dependent on energy for pumping, treatment and supply • Population is dependent on energy for heating and cooling and many other functions
ICT	• Energy for all services • Communication • Transport for maintenance workers	• All sectors depend on ICT
Transport	• Infrastructure of roads, buildings, stations etc. for travel • Energy infrastructure for fuel and electricity • Drainage infrastructure to prevent flooding • Internal dependencies with and across modes (road, rail, sea, and air)	• All sectors depend on transport
Water	• Energy for treating, pumping and processing • ICT for control systems • Transport for workers and supplies for processing	• All workplaces and homes require water for people and sanitation • Cooling water for some energy infrastructure • Energy infrastructure may depend on water for generation • Food production requires water
Emergency Services	• Transport (all modes) for safe and rapid evacuation, and emergency supplies • Energy to manage emergency pumps to relieve flooding and operate flood controls • Health infrastructure to respond to emergency situations • Water infrastructure to extinguish fires	• All sectors depend on emergency services for safety and security during emergency situations

	• ICT to respond effectively to emergency situations • Social and domestic infrastructure to provide security for population	

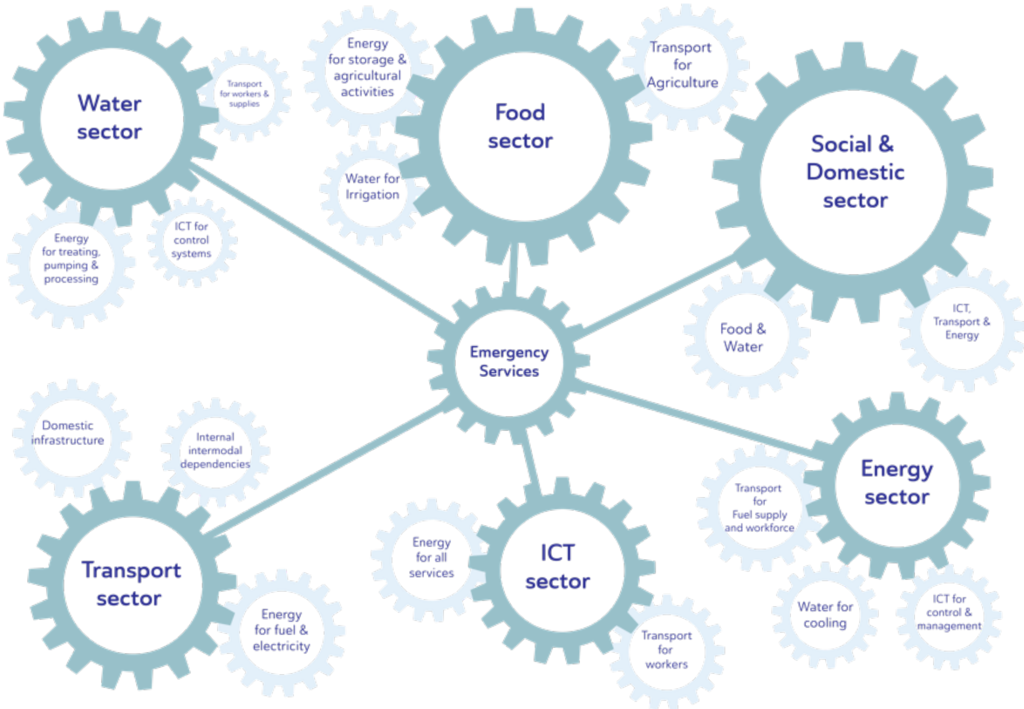


Figure 24. Sectoral interdependencies

In determining the degrees of vulnerability of systems and services, typical questions to ask include:

- What are the vulnerabilities that lead to impacts?
- Which impacts cause the greatest suffering?
- Who is affected the most?
- Which impacts are the most difficult to deal with?
- How are livelihoods affected?
- Which sectors are affected the most?

By understanding the vulnerability of the infrastructure system and services to the primary and secondary hazards, it is possible to provide more accurate and timely warnings that would protect a population from existing weaknesses in infrastructure that compound the threat of mortality and morbidity posed by the initial hazards. Collapse of buildings, bridges, and roadways, loss of ICT, electricity, transportation and sanitation frequently contribute to creating the circumstances leading to subsequent disasters.

6.6 Step 6: Translating hazards forecasts into impact-based forecasts

It is possible and indeed advisable to start simple. Lack of comprehensive databases should not prevent starting impact-based forecasting. Limited data will affect the certainty level in any impact-based forecast and warning, but there are ways to generate impact-based forecasts and warnings even where data and infrastructure are scarce. Past event analysis to link the magnitude of the hazards to impacts they caused can be a useful tool to provide an estimate of potential impacts of similar hazards in the present time. A lack of data, from observation networks, modelling or socio-economic datasets, does not mean that impact-based forecasting is not possible.

The first step of translating hazard forecasts to impacts would be a subjective process, based primarily on the experience of the members of the partnership. Before embarking on advanced forecasting techniques and quantitative estimates of vulnerability, it is necessary to learn how to translate a hazard into clear information about the likely impact (Figure 25).

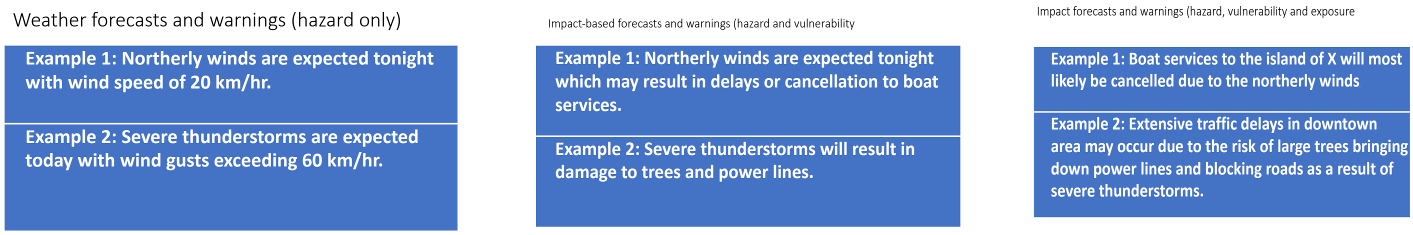


Figure 25 Examples of weather forecasts and warnings (hazard only), impact-based forecasts and warnings (hazard and vulnerability) and impact forecasts and warnings (hazard, vulnerability and exposure)

It is important for NMHSs to gather information and prepare a database of the impacts of various weather-related hazards in the country. If this is a new activity, it is essential to gather as much historical information about the impacts of past hazards as is possible while adding the impacts of new hazards as they occur. In gathering historical datasets for impacts (e.g., floods, mudslides, wind damage) of a particular type of hazard (heavy rainfall, strong wind) asking the following key questions is helpful:

- What were the impacts of the hazard?
- How long ago did the impacts occur?
- Where were the impacts observed?
- How severe was the impact?
- What was the magnitude of the hazard to cause a severe impact (e.g., how much rain fell and what was the intensity of the rainfall, how strong was the wind)?
- What is the frequency and geographic distribution of impacts from a particular hazard?
- How is the nature of the particular hazard expected to change in the future due to climate change and climate variability (e.g., more intense storms leading to more frequent flash floods)?

As the steps advance, more advanced forecasting tools, such as probabilistic forecasts and visualization tools such as GIS, may need to be introduced in producing impact-based forecasts and warnings. These more advanced steps would build on and expand the basic subjective forecasting system by including integrated meteorological, hydrological and impact-based modeling, leading to GIS-enhanced impact-based forecasts and warnings.

Where possible, the time needed to generate a forecast or warning can be reduced by automation. Different types of software have been developed which allow automated generation of warnings based on the hazard and anticipated impacts. These tools enable reducing the warning production time and allow dedicating more time for dissemination and communication with users.

6.7 Step 7: Developing the Risk Matrix

A risk matrix links the severity of the impact with the likelihood of impact occurring (Figure 24). Hazard information along with vulnerability and exposure data is used to assess the *level of impact*. Uncertainty in the hazard, and uncertainties in vulnerability and exposure data, determine *how likely the impacts are to occur*.

Outputs from hydro-meteorological models will be used as input to a hazard impact model that is designed to translate natural hazard risk into economic, social and physical outcomes. This would require understanding and visualization of the location and vulnerability of key assets and critical infrastructure. The actions to be taken depend on the likelihood and severity of the scenario, with a colour assigned based on an assessment of the risk, which has four categories: very low (<20% green), low (20-40% yellow), medium (40-60% orange) and high (>60% red) (Figure 26). The percentages illustrate examples of assigning quantified risk levels to each colour. Consequently, a flood, which is highly likely to occur with severe impacts, is colour-coded red for high risk. The designation of the colours is subjective and dependent on combining meteorological and hydrological information with sector specific knowledge. Climatology-based regional and/or seasonal specific thresholds can provide the forecaster a valuable starting point for discussions in estimating the severity and the impact of an event.

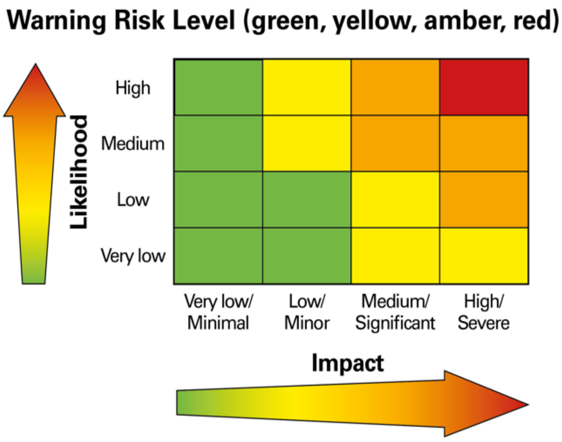


Figure 26 The risk Matrix

In the case of flood risk, discussion may involve water resource managers, irrigation experts, dam operators, transport, public works as well as disaster managers. The level of risk can be assigned to a specific geographical location – a grid box within a map (see Figure 18) – thereby building a dynamic risk map, which highlights the areas, which may require specific interventions to mitigate the risk – house-to-house notifications, evacuation to shelters, cell broadcasts, etc. In particular, it will help civil protection to deploy resources effectively.

The Risk Matrix is dynamic. Before and during a weather event, the hazard forecast certainty may change to be more or less certain. It is also possible for the impact of a hazard to increase without altering the likelihood of the hazard; this occurs when there is a forecast change in timing of the hazard, for example, if the timing of a hazard (heavy rainfall) changes from night-time to the morning "rush hour", the same rainfall event will have a greater impact on the people living in a particular location. The assessment of the likelihood and level of impacts will also change, thus, the matrix is a means to progressively express changing expectations of risk as a function of varying exposure, vulnerability and hydrometeorological likelihood.

Users can follow the forecast and adjust decisions and actions required in response to the changing certainties and severity levels. It is therefore important for decision-makers to have access to the risk matrix as well as the colour-coded level of the warning. Warnings for different hazards should be consistent; it is recommended, therefore, to avoid creating alternative classifications for warnings since that may cause confusion among those at risk.

In the case of a tropical cyclone, for example, the flood hazard would be identified based on trajectory and intensity of the event. The risk matrix combines the flood and vulnerability information for each identified geographical section. As the system evolves, the severity of the risk will change enabling an adaptive response to the event. Each of the risks associated with the secondary and tertiary hazards would also be computed.

In this way, it is possible to construct the matrix by carefully and continuously monitoring the development of the hazard, its direction of movement and its intensity, although ideally, the likelihood is best determined from a probabilistic forecast using ensemble techniques. The level of the impact is determined from knowledge of vulnerability and exposure. Together, these determine the severity of the warning using a four-colour system – green, yellow, orange, red.

How the Risk Matrix should be used is illustrated in Figures 27-31, in the case of a tropical cyclone. As the forecast confidence in the intensity and track of the cyclone increases, the position of the "X" in the box changes.

Likelihood					
	High				
	Med				
	Low				
	Very low				X
		Very low	Low	Med	High
	Impact				

Figure 27. Four days before the tropical cyclone arrives

Likelihood					
	High				
	Med				
	Low			X	
	Very low				
		Very low	Low	Med	High
	Impact				

Figure 28. Three days before the tropical cyclone arrives

Likelihood					
	High				
	Med			X	
	Low				
	Very low				
		Very low	Low	Med	High
	Impact				

Figure 29. Two days before the tropical cyclone arrives

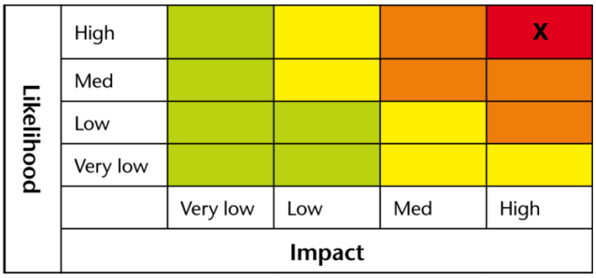


Figure 30. Two days before the tropical cyclone arrives

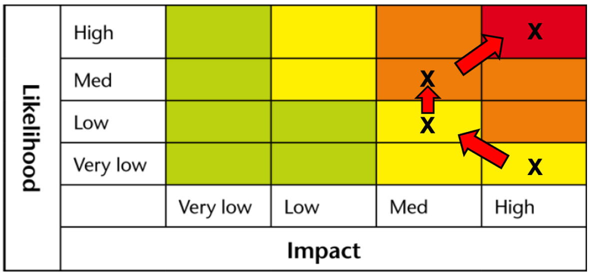


Figure 31. Path of risk over several days

In this illustration, it is important to note that while the position of "X" may be in the yellow box (Figure 27), the impact of the hazard is medium, the same as it would be when "X" has shifted to an orange box (Figure 29). The only difference is the change in likelihood of the impact due to more certainty in the forecast. Just because the "X" is in a yellow box, it should not be assumed that the impact is any less than that when it is in the orange box. Another point to note is that the use of the red box should be reserved for occasions when both the likelihood and severity of impact are high – this box should not be overused.

At this stage, two types of warning maps will exist – one set providing warnings of the severity of the meteorological or hydrological hazards and another set of warnings of the impacts of the meteorological or hydrological hazards. The latter may differ substantially from the former depending on vulnerability and exposure of people and assets. They will also differ from one sector to another because each will have its own unique vulnerability and exposure characteristics.

This concept is very well explained in the video based on the UKMO national severe weather warnings matrix (link shown below).

https://www.drivecreativestudio.co.uk/project/weather-warnings-matrix-explainer-video/

Using the matrix, the NMHS will be able to communicate the likelihood of impact of a potential impact of a hazard or multiple hazards and the severity of impacts. This would guide the NDMO to make effective and timely decisions that factor in potential risk and impacts.

Training should be provided to all partners and particularly to weather forecasters and hydrologists, NDMOs, and PWS advisors in the understanding and application of the Risk Matrix, which is an important tool in an impact-based warning system. A risk matrix can be a useful communication tool for users such as NMHSs, disaster risk reduction and management agencies, civil protection, and humanitarian organisations. However, care should be taken in using a risk matrix when dealing with anyone who does not have knowledge or understanding of risk assessments.

The lead time for a forecaster to produce a forecast or warning will vary depending on the type of hazard and the corresponding forecast or warning. Rapid onset hazards require rapid issuing of impact-based forecasts and warnings to maximise the time available to users to process and act. Allowing sufficient time available to users to interpret and act upon the information is just as important as taking the time for producing the forecasts.

Factors to consider when identifying lead times for forecasts and warnings include:

- How long will it take to produce the impact-based forecast or warning?
- How long will it take to disseminate the forecast or warning?
- How much time will it take for users to process the information?
- How long will it take to carry out anticipatory actions?

The time needed to complete response actions influences the required lead time for forecasts and warnings.

Forecasts and warnings should be updated when a significant change in the forecast occurs. This could be a change in the magnitude of the forecast hazard, which affects the level of impact, or the direction, which can affect which area will be prioritised for assistance, or a change in conditions on the ground affecting vulnerability or exposure, which affects the level of impact. What constitutes a significant change will vary from hazard to hazard and user to user.

The training of NMHSs and NDMOs personnel should contain examples from various parts of the world where successful harmonization of colour coding and their meaning has been achieved.

6.8 Step 8: Developing Impact Tables

An Impact Table should be developed for each hazard and for each sector. This requires expert knowledge of the hazard and the likely impact on a specific sector. At its most basic it would rely on expert knowledge rather than quantitative data. In the case of flood risk, this may involve water resource managers, irrigation experts, dam operators as well as disaster managers. Examples of an impact table are shown in Tables 6 and 7. In this case the information is still general but can be more geographically specific and targeted to particular groups at risk. Learning how to construct impact tables for various hazards and sectors by partners should be part of an IBFWS capacity building plan.

Table 6 Example of a flood impact matrix for the public

Flood Impacts Matrix for the public			
Very Low impacts	**Low impacts**	**Medium impacts**	**High impacts**
• Generally, no impact expected • Isolated and minor flooding	• Localized flooding of land and roads • Localized flooding could	• Flooding affecting properties and parts of communities	• Widespread flooding affecting significant numbers of properties and whole communities

of low-lying land and roads • Isolated instances of spray/wave overtopping on coastal defenses • Little or no disruption to travel although wet road surfaces or waterlogging could lead to difficult conditions • Isolated damage to vegetation due to wind	affect individual properties • Individual properties in coastal locations affected by spray and/or wave overtopping • Localized disruption to key infrastructure identified in flood plans (e.g., rail and utilities) • Local disruption to travel • Localized damage to properties due to wind	• Damage to buildings/infrastructure is possible • Possible danger to life due to fast flowing/deep water/wave and storm surge overtopping/wave inundation, landslides and wind • Disruption to key infrastructure services identified in flood plans (e.g., rail, utilities and hospitals) • Disruption to travel is expected. A number of roads are likely to be closed • Outbreaks of illnesses caused by waterborne diseases possible • Isolated food shortages • Localized water contamination	• Collapse of buildings/infrastructure is likely • Danger to life due to fast flowing water/ deep water/ wave, storm surge overtopping and wave inundation, landslides and wind • Widespread disruption caused by loss of infrastructure identified in flood plans • Large scale evacuation of properties may be required • Severe disruption to travel. Risk of motorists becoming stranded. • Large scale evacuation of people may be required • Severe disruption to travel. • Outbreaks of illnesses caused by waterborne diseases expected

Table 7. Example of a wind impact matrix for the public/first responders

Wind Impacts Matrix for the public/first responders			
Very low impacts	**Low Impacts**	**Medium impacts**	**High impacts**
• Damages to billboards • Falling tree branches • Interruption of outdoors normal activities	• Minor disruption to travel • Some injuries • Isolated loss of telecommunication and electrical power • Isolated damage to roofing • Falling trees blocking roads • Traffic disruption	• Localized loss of communication and electricity supply due to gusty wind • Localized damaged power lines • Localized business disruption (industrial zone, urban areas) • Localized disruption of schools • Diversion of aircraft • Danger to life from flying objects – injuries (physical trauma) • Air and sea search and rescue disrupted	• Widespread damage to weak structures – houses and commercial buildings • Widespread uprooting of trees • Widespread power loss due to fallen power lines • Wind-driven waves damage coastal structures causing injury • Widespread delays to public transportation (Air, Road, Rail, Ship, Ferry).

		• Localized disruption to ground transport • Localized destruction of poorly built structures • Falling lamp posts	• Danger to vehicles on roads • Electrocution from falling power lines • High risk to aircraft • Widespread loss of fishing boats, and other shipping • Search and rescue impacted on a large scale • Severe injury • Death

6.9 Step 9: Developing Advisory Tables

A final component of the IBFWA production process is to provide advice on what actions to take. The key purpose of producing impact-based forecasts is to enable better decision making by end users for risk reduction. A user may be able to take different levels of protective or beneficial actions according to how high the probabilities of the impacts are. Many situations are more complex where there are multiple categories or potential responses, and the best outcome is likely to come from a strong partnership between the user and the NMHS. This helps the NMHS to better understand user needs and the user to understand the forecasting capability.

Advisory messages should be tailored to specific needs of each stakeholder. Disaster risk management agencies and other government departments, humanitarian agencies and sector specific users, will most likely have developed plans for early actions that describe clearly the type of actions these institution need to take based on an impact-based forecast service. In the case of the general public more care should be taken to add behavioural recommendations to the expected impact since people are more likely to engage in actions which will reduce impact when given additional advice and guidance on mitigative actions. Figure 32 illustrates the relation between the risk matrix and the advisory matrix for a particular hazard. The color coding for levels of impact corresponds to that of the advisory matrix, with the level of precautionary advice matching the level of anticipated impact.

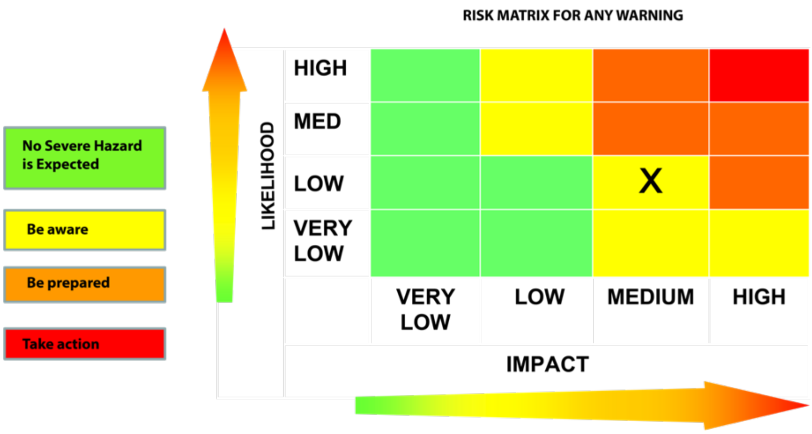


Figure 32. Advisory matrix and risk matrix color coding correspondence

Examples of alerts and warning advisories and actions are shown in Table 8 (adopted from Met Office).

Table 8 Advisory matrix for the public, relating warnings and actions to the probability of an impact based on an impact risk matrix. The levels reflect the color coding of the risk matrix

Advisory Matrix			
Very low risk	**Low risk**	**Medium risk**	**High risk**
Example of flood risk for general public associated with a tropical cyclone			
STATEMENT: Unlikely that the tropical cyclone (Event) will affect the designated region **ACTION:** Keep an eye on the weather and flood forecasts	**ADVISORY:** Likely that the tropical cyclone will cause some limited flooding and wind damage in the designated region **ACTION:** Remain alert and ensure you access the latest weather forecast for up-to-date information. Follow advice on rough seas (fishermen, hotel operators, pleasure crafts) Prepare to take action to protect life, livelihood and property in the designated region.	**WARNING:** Likely that the tropical cyclone will cause widespread flooding and wind damage in the designated region **ACTION:** Secure property and livelihood assets, such as boats. Be prepared to evacuate. Be aware of the potential risk of landslides and flash floods in your area. Do not venture into the sea and certain beaches affected by coastal inundation Follow civil protection orders. Maintain radio/media watch for latest updates.	**WARNING:** Certain that the tropical cyclone will cause widespread flood and wind damage in the designated region **ACTION:** Evacuate if ordered to do so by civil protection Do not venture into the sea and certain beaches affected by coastal inundation Be prepared for extraordinary measures to protect life and property

An advisory matrix for a specific sector would include more detailed information (Table 9)

Table 9 Advisory matrix for dam operations, which relates warnings and actions to the probability of an impact based on an impact risk matrix.

Advisory Matrix			
Very low risk	**Low risk**	**Medium risk**	**High risk**
1. Example of flood risk for dam operations associated with a Tropical Cyclone event			
STATEMENT: Unlikely that the tropical cyclone (Event) will affect the designated region **ACTION:** Keep an eye on the weather and flood forecasts	**ADVISORY:** Likely that the tropical cyclone will cause some limited flooding and wind damage in the designated region **ACTION:** Expected inundation levels do not require any action, but beware of the potential for the risk to increase	**WARNING:** Likely that the tropical cyclone will cause widespread flooding and wind damage in the designated region **ACTION:** Activate standard operating procedures associated with an orange alert to mitigate the risk of damage to the dam and appurtenant structures	**WARNING:** Certain that tropical cyclone will cause widespread flood and wind damage in the designated region **ACTION:** Activate standard operating procedures associated with a red alert to mitigate the risk of damage to the dam and appurtenant structures. Mitigate the risk of

		and mitigate the risk of exacerbating flooding downstream of the dam. SOPs will include all measures to warn others potentially impacted by the dam operations.	exacerbating flooding downstream of the dam. SOPs will include all measures to warn others potentially impacted by the dam operations

6.10 Step 10: Communication and Dissemination

An accurate forecast is not very useful if it is not communicated effectively and is not received in time to allow risk or impact mitigation measures to be taken. Effective communication of forecasts or warnings is achieved when these products are disseminated in a timely manner, are free of jargon, easy to understand, consistent, credible, and relevant, to enable users to make decisions and take actions that result in the reduction of impacts. Communicating impact-based forecasts requires a detailed understanding of the target audience[23]. Communication strategies should be developed to decide:

- What to communicate to whom?
- What channels of dissemination and communication are most effective for which target groups?
- How to communicate different forecast scenarios and uncertainty?
- What methods and formats for communicating uncertainty should be used for different media?

The following questions will help develop the most suitable and effective strategy by identifying the audience characteristics and the best communication tools to use:

i. Is the forecast or warning aimed at the public or sector specific users (e.g., government ministries/agencies, business, disaster managers, humanitarian sector, NGOs, UN agencies)?
ii. What language(s) is the audience familiar with?
iii. How do users access forecasts and warnings?
iv. What business continuity measures need to be considered if the normal dissemination routes fail?
v. How should the information be presented? What visuals, word choices, and colour schemes are culturally relevant, understandable, and practical?
vi. How can levels of risk be communicated to promote decision-making and action?
vii. What do the users need to know? (e.g. what infrastructure is likely to be impacted, what crops are likely to be damaged, what population group is likely to be impacted?)

6.10.1 What to Communicate?

In practice, the level of information to answer this question will vary. Tailoring impact-based forecast communication to different audiences makes an important difference in how effectively the recipient can act on the communicated information. Table 10[24] shows examples of the type of information that users of impact-based forecasts and warnings need to know.

[23] The Future of Forecasts: Impact-based Forecasting for Early Action. Met Office, IFRC 2020.

[24] Adopted from Met Office, IFRC. 2020

Table 10. The impact information needed by different users

Question	Public/Individuals	Sector-Specific
What is going to happen?	Summary of the hazard *impacts*, avoiding technical terms	• Summary of the hazard • May include a technical summary with detail of the weather/climate parameter, such as magnitude of the hazard, probability/likelihood of event • What are the potential impacts?
When will it happen?	• When will impacts begin? • When will impacts stop occurring? • Timing and location	• When will impacts begin? • When will impacts stop occurring? • Timing and location
How bad will it be and where?	• Clear, jargon-free explanation of risk, focussed on impacts	• Assessment of the risk • May include risk matrices, risk maps/ intervention maps • Where will impacts take place? • How severe will the impacts be?
What can I do to reduce impacts?	• Advice and guidance on what actions can be taken to prepare	• Organizations will have action plans or response plans in place in response to warnings. They will need to activate these plans.

Choice of communication channel through which users access warnings influences the design of impact-based forecasts and warnings. For example, forecasts and warnings designed to be viewed as a paper document should have a different appearance to a forecast or warning designed to be used on a mobile app, in a text message, or on a website. Similarly, colour can be used to advantage for better communication of information. However, care must be taken in using colour to make sure recipients are fully informed of the level of severity of the impact represented by each color, and vision deficiencies which can affect how users actually see different colours should be taken into consideration. Text sizes and fonts can also affect how easily something can be read and understood.

6.10.2 Communicating Different Scenarios and Forecast Uncertainty

A lot of the technical jargon taken for granted within NMHSs is often not understood by outside audiences. As a general rule, when composing forecasts and warnings, great care should be taken to use language appropriate for the audience. All users should be asked to provide feedback on any proposed language and designs.

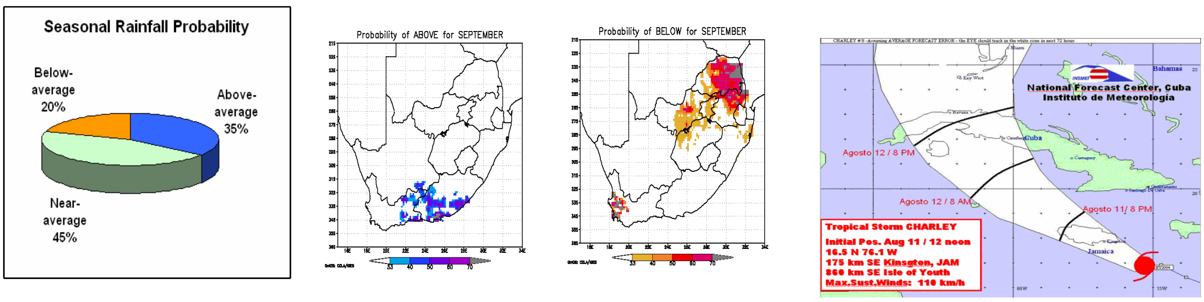
This becomes even more important in the case of impact-based forecasts when more terminology is used due to the nature of such forecasts which include uncertainty. For any given climate or weather event for which a forecast has been produced, there are usually a range of possible forecast outcomes. For example, as a storm develops and begins to move towards a major city, a number of forecast outcomes will be possible for that city. These may spread across a range from a high likelihood of the storm to pass nearby the city but with no severe impacts to the city, to forecasts of low likelihood which will bring the storm straight through the centre of the city, with severe damaging impacts. How to communicate these scenarios? The first scenario is the most likely forecast outcome but with no or very little impacts, and the second is the much less likely forecast scenario but with far more severe impacts. An impact-based warning for the less likely but more impactful scenario will allow the public at risk to know that very severe impacts may occur in their area, so they can prepare to take action. However, the forecast should be continually updated by closely monitoring the weather situation and the updates should be immediately communicated to the first responders and the public.

All forecasts contain uncertainties and this is especially the case with impact-based forecasts and warnings; the method of communicating those uncertainties will vary depending on the target audience and level of user sophistication, and the media used for communication.

It is important to keep in mind that different users will have different requirements for uncertainty information as well as different levels of understanding (Table 10). For some, particularly those involved in emergency response, detailed quantitative estimates of uncertainty are required. Specific risk reduction, preparedness and response plans may be in place that describe certain actions to be taken according to defined thresholds. For example, a community evacuation plan may be activated if the probability of very strong winds being experienced increases beyond 20%. Informed users (e.g., first responders, disaster managers) of uncertainty information are aware of the underpinning reasons for uncertainty, and NMHSs – when providing this information – can use technical language and speak in some detail. The use of relatively complex graphics is also possible. For less informed users (e.g., general public), NMHSs need to be quite careful about the use of complex information. Such users may be less likely to understand the sources of uncertainty and may prefer simple messages and graphics[25].

As previously mentioned, color is a very powerful tool for conveying information and meaning, however, it needs to be used carefully. Color can be used in visual communication (television, internet, mobile application), but if presenting forecasts in a narrative form via radio or if telephone is the only way of reaching users, relaying uncertainty information must be clear and consistent in terminology. It is important to take language and cultural differences into account in defining standardized terminology for uncertainty information, to avoid confusion. Terminology such as “probable”, “possible”, “chance of” should be clearly defined to the user and be used consistently.

Simple graphs can be a useful way to present uncertainty information in quantitative terms. The following examples (Figure 31) show the use of graphics in the form of a pie chart, a probability map for above and below normal rainfall, a cyclone track uncertainty cone, a wind-speed probability map, a fan chart of a temperature forecast, and icons with a probability value. Care should be taken to explain what the “average” is when using “above” or “below” average terminology.



[25] Guidelines on Communicating forecast Uncertainty WMO-TD No. 1422

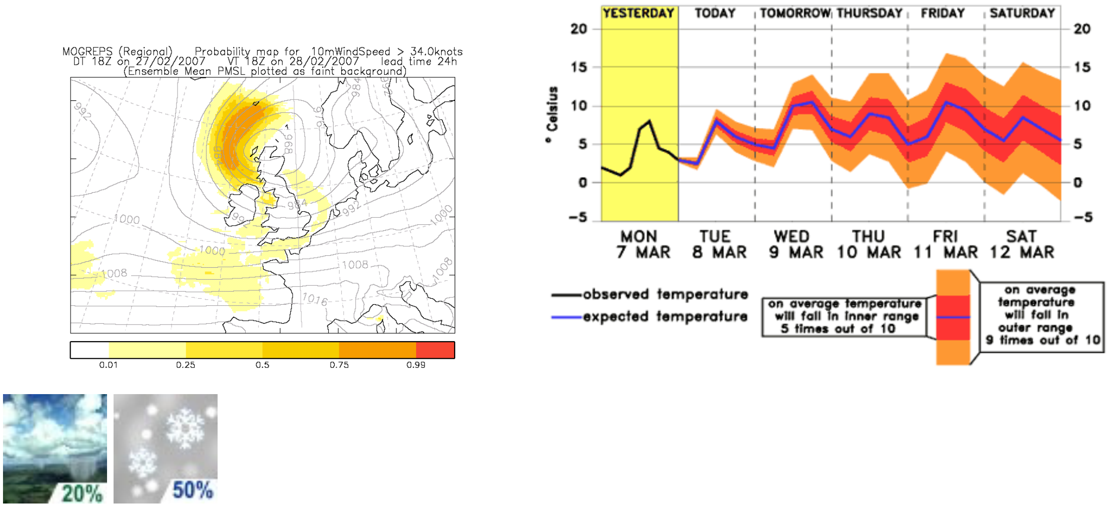


Figure 33 Example of different graphics to express uncertainty from left (pie chart, probability rainfall forecast of above and below average, cyclone track uncertainty cone, wind speed probability map, a fan chart of temperature forecast, icons with probability values)

If icons are used for a quick pictorial image on television or a web site, the uncertainty information in numerical terms (e.g., as a probability) could be superimposed on the icon, as shown in Figure 33. The WMO *Guidelines on Communicating Forecast Uncertainty (WMO-TD No. 1422)* provide a wealth of information on the use of various tools in communicating uncertainty, which are especially useful for providing clarity in conveying uncertainty in impact-based forecasts.

It may be appropriate to issue additional information, alongside the impact-based forecast or warning, to further explain uncertainty in a forecast situation. For example, graphics issued alongside weather warnings in the UK show the possible tracks of storms. The graphics issued ahead of impactful storms help government and civil protection agencies understand how the track of the storm could change and what that would mean in terms of where the most severe impacts would occur. The same method is used for other hazards, such as snow and heavy rain. These are shown in Figure 32[26].

[26] The Future of Forecasts: Impact-based Forecasting for Early Action. Met Office, IFRC2020.

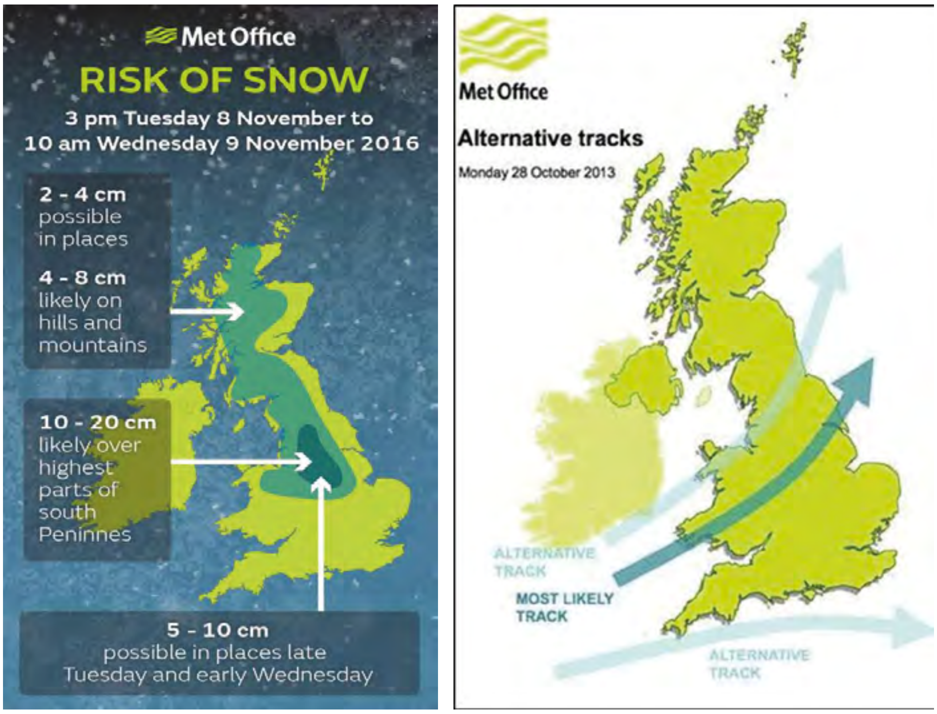


Figure 34 Examples of showing possible tracks and use of wordings alongside color in impact-based forecasts

As pointed out above, the choice of method and format for communicating uncertainty information will greatly depend on the media being utilized. For face-to-face weather briefings, or radio interviews, or wherever the forecast can be provided verbally, the use of plain language and narrative can be effective. Where the forecast is presented in writing, then the forecaster should ensure that their description of uncertainty (e.g., use of terms such as “a chance of”) is confined to pre-defined or well-understood terms. Graphical depictions of forecast uncertainty are a very useful presentation style and are especially suitable to web-based display. These can be accompanied by explanatory information to help users interpret what can be rather complex information. For television, the options are more restricted due to the limited broadcast time available, but some maps or graphs may be helpful to get the message across.

6.11 Step 11: Validation

Validation and verification are important components of any forecasting system. Verification provides critical insight into the accuracy and effectiveness of impact-based forecasts and warnings and drives improvements. Verification schemes need to assess whether an impact-based forecast or warning gave effective information to the intended audience.

One of the main purposes of impact-based forecasts and warnings is to drive early actions and mitigate impacts. An effective impact-based forecast and warning should therefore result in reduced impacts. The mitigating actions, based on the impact-based forecast and warning, must be taken into consideration during any verification. For example, the forecast impacts associated with flooding will differ from the actual impacts caused by the flooding, if steps are taken to evacuate. If this action is not recorded, the forecast may be assessed incorrectly. Table 11[27] shows issues that need to be considered when conducting a verification of an impact-based forecast.

[27] Ibid

Table 11 Issues to be considered in impact-based forecasts verification

Component to verify	Questions to answer based on several forecasts	What verification information is needed	Sources of verification information
Type of hazard	Was the observed hazard type different from the forecasted hazard type?	Observed hazard type	• National hydrological and meteorological service • Government • Civil Protection Agencies • Disaster Risk Reduction Agencies • Humanitarian sector • Media: TV, radio, newspaper • Social media • Webcams • Traffic cameras • Community groups/individuals
Magnitude of hazard	Was the magnitude of observed hazard different from the forecast hazard magnitude? Did this cause people to act "unnecessarily" or to "fail to act"?	Observed hazard information	• National hydrological and meteorological service • Government • Civil Protection Agencies • Disaster Risk Reduction Agencies • Humanitarian sector • Media: TV, radio, newspaper • Social media • Webcams • Traffic cameras • Community groups/individuals
Forecasted impacts	Did the forecasted impacts occur? Were there other impacts in addition to those in the forecast that were more relevant?	Observed impacts	PostDisaster Needs Assessment (PDNA), satellite images, humanitarian disaster impacts report etc.
Severity of impact	Was the severity of observed impacts the same as the severity of forecasted impacts? Are there systematic errors in the underlying datasets?	Observed impacts	• Government • Civil Protection Agencies • Disaster Risk Reduction Agencies • Humanitarian sector • Media: TV, radio, newspaper • Social media • Webcams • Traffic cameras • Community groups/individuals
Forecast area of risk	Did the impact- based forecast and warning identify the area or locations at risk accurately?	• Location of observed impacts • Extent of area affected by impacts	• Government • Civil Protection Agencies • Disaster Risk Reduction Agencies

			• Humanitarian sector • Media: TV, radio, newspaper • Social media • Webcams • Traffic cameras • Community groups/individuals
Forecast validity time	Did the impacts occur in the time window communicated in the forecast or warnings?	Time observed impacts occurred	• Government • Civil Protection Agencies • Disaster Risk Reduction Agencies • Humanitarian sector • Media: TV, radio, newspaper • Social media • Webcams • Traffic cameras • Community groups/individuals
Clarity of forecast/ warning	Was the forecast or warning easily understood by users? Were there any misinterpretations?	Feedback from users	• Government • Civil Protection Agencies • Disaster Risk Reduction Agencies • Humanitarian sector • Media: TV, radio, newspaper • Social media • Community groups/individuals
Effectiveness of forecast/warning	Did recipients take action based on the information provided in the warning? Would the provision of different information have better encouraged action?	Feedback from users	• Government • Civil Protection Agencies • Disaster Risk Reduction Agencies • Humanitarian sector • Media: TV, radio, newspaper • Social media • Community groups/individuals

Surveys after a weather event can help establish how well impact-based forecasts and warnings performed. NMHSs can use online surveys, social media campaigns, community events, and workshops to learn more about impacts and gather feedback on forecast and warning performance. Additionally, if a partner organisation is conducting assessments within communities, they may be able to seek feedback on behalf of the NMHS.

NMHSs should create an archive of impact-based forecasts and warnings and any related data. Forecast verification takes into account many forecasts and events over a length of time, as the result from a single forecast error should not be taken as an indication that the entire system is not useful.

6.12 Step 12: Impact forecasts

A final step would be the evolution from impact-based to impact forecasts where exposure is explicitly included in the prediction system. This final step creates a highly dynamic warning and response system that reflects the actions of those at risk as well as the efforts to reduce their exposure to hazards. This would mean that although hazardous situations may exist and people remain vulnerable, their actions reduce their exposure and therefore the impact.

As mobile applications increasingly become universal, and highly localized forecasts become more easily accessible, individuals will increasingly be able to receive warnings tailored to their specific circumstances. This will give more detailed information about a specific threat and actions to be taken to protect lives and livelihoods. The level of detail would complement the warnings issued by the national and local authorities, enabling a more effective, personalized response. For example, the special needs of the individual may prompt early evacuation by the local authority or recommendations to shelter in place, depending on the integrity of the individual's home. The reduced exposure would also reduce the warning level, so that it would be possible to monitor in real-time changing risk levels of the population, enabling responders to target their activities to people at higher risk.

The various levels of impact-based forecasts and warnings are summarized in Table 12.

Table 12. Transition to impact forecasting

Type of Forecast & warning	Essential ingredients	Service Provider(s)
Impact-based (basic)	Based on relationship between the physical hazard and damage to infrastructure	Primarily government operated meteorological, hydrological, and geophysical agencies
Impact-based (advanced)	Based on vulnerability of infrastructure, social determinants (vulnerability of people) as well as past damage assessments. Multi-hazard impact-based forecast and early warning system	Disaster management agencies, local authorities, nongovernmental organizations, agencies responsible for forecasting and advising on physical hazards, economic sectors, media– working together to create an integrated service
Impact	Explicit inclusion of exposure based on location using mobile devices allowing the tailoring of the impact information by the user to their individual needs and permits direct feedback to responders and disaster managers using a social media-based system	As above with full integration of first responders

7 Standard Operating Procedures

A Key element of effective impact-based warning services is sound Standard Operating Procedures (SOPs), which codify the roles and responsibilities of all stakeholders and actors in all possible scenarios (Figure 35). Early briefing prepares the decision makers to act ahead of joint-response mechanisms and prior to issuing public warnings.

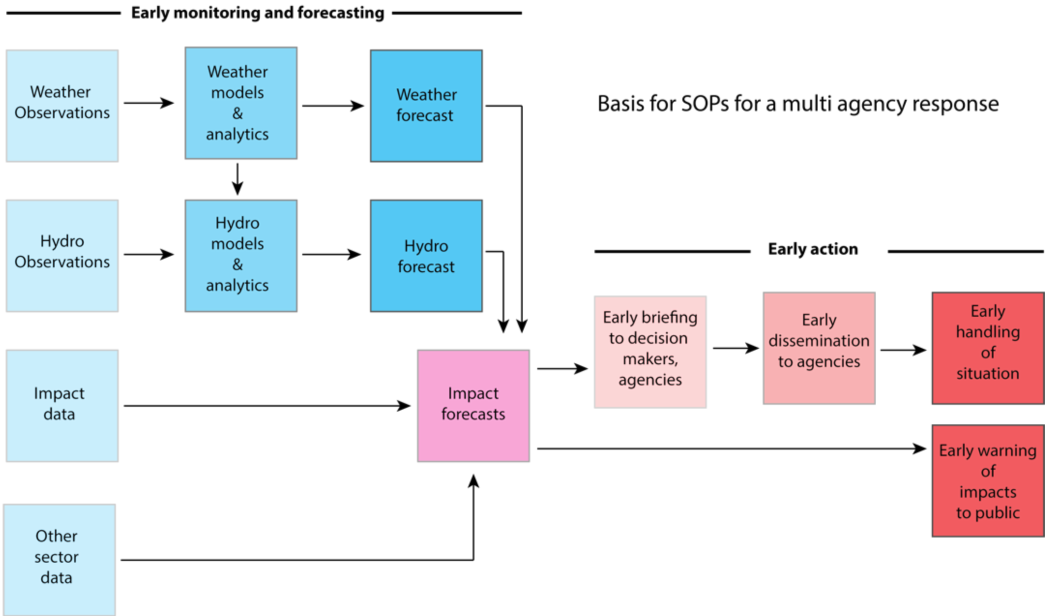


Figure 35. Basis for SOPs for a multi-agency action and response

The person in charge of the public weather service in an NMHS is normally responsible for disseminating routine weather information including warnings to the public. This may also be the case for impact-based forecasts and warnings dissemination. It should, however, be noted that the final dissemination of warnings to the public may be governed by the governmental structures and practice which determine the flow of the information. For example, while in some countries the NMHS is responsible for and authorized to disseminate the warnings directly to the public, in some others, the warnings are disseminated through the disaster management organizations, or maybe even directly through the office of the minister in charge of meteorology or disaster risk management. While the structures and legal mechanisms in each country should be respected, the most important point is that procedures should not introduce delays and hinder the dissemination of highly perishable information (e.g., warnings of a flash flood expected to impact a city at rush hour), hence putting the public and responders in unnecessary danger.

8 Conclusions

The ability to understand and respond effectively to warnings is central to a resilient population. Impact-based forecast and warning services complement the traditional role of meteorological and hydrological forecasting services by translating technical knowledge into information of direct relevance to those affected. Advances in the understanding of the atmosphere-ocean-land system coupled with advances in numerical prediction and observation of this system mean more timely and accurate forecasts of hazards. The use of ensemble prediction techniques gives insight into the likelihood of a hazard, and this knowledge, coupled with information about what and who is likely to be affected, can be used to provide more actionable warnings.

It should, however, be kept in mind that impact-based forecasting is not a perfect process. Where impact-based forecasting is already established, progress is iterative. The process should be reviewed at regular intervals to ensure forecasts and warnings remain fit for purpose. Monitoring and applying best practice from partners and other impact-based forecasting practitioners, new scientific research into weather and climate modelling, and assessing and communicating risk will also help to improve impact-based forecasting. The experience of those countries, which have developed and used these techniques, is invaluable in helping others.

Validation and verification of impact-based forecasts and warnings are essential to improve the forecasting systems and processes. Verification provides a mechanism for collecting regular feedback from recipients. However, impact-based forecasting and warning systems need different methods of verification than those applied to objective forecasts. Here the emphasis is on the utility of the forecast, not only the accuracy of the underlying meteorological or hydrological prediction. This requires agreement among stakeholders and partners on the level of utility and cooperation to analyse and evaluate events to improve the warning system. Verification training needs to be modified to satisfy this requirement.

Building the capacities of the relevant staff of NMHSs, NDMOs and partner agencies to conduct these various activities for implementing IBFWS is critical.