THE FUTURE OF FORECASTS:
IMPACT-BASED FORECASTING FOR EARLY ACTION

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FOR EARLY ACTION

FOREWORDS

WE OFTEN TALK about the desire to go the 'last mile' and narrow the gap between science and action. It was this desire that provided the catalyst for a change to impact-based thinking.

The core tenet of this paradigm shift was to bring differing communities together, to provide the mechanisms and collective desire to make a difference on the ground, to save lives, and to reduce distress and disruption. That was the idea, and it worked.

The most valuable part of impact-based warning is the relationship between partners, which creates a level of trust that enables quick decision-making under pressure. This is both a strength and a weakness, as any gap in these relationships could dramatically reduce the overall impact of the warnings.

It also suggests that citizens' trust may be dependent on who delivers the information and what relationship they have with the user. Maya Angelou is quoted as saying that 'People forget what you say, forget what you did, but not how you made them feel'. The question is 'how do others feel?' when they engage with the provider of impact-based forecasts, and how do we allow others to resonate with us so they feel empowered and enriched from the experience?

Our warnings often focus on single hazards and their direct consequences. People living in well-built homes, in urban settlements, generally have little to fear from the direct impacts of most hazards (except perhaps floods). However, urban populations, particularly coastal megacities, can be extremely vulnerable to indirect impacts such as the loss of power, water, communications, transport and even food.

All this at a time of great environmental and societal change. The next frontier could be unlocked through the science of weather and climate or, equally, through embracing new technologies (data analytics and artificial intelligence), and developing the cognitive intelligence on future climates to anticipate weather impacts and inform actions today.

No doubt we could all become masters of our weather-impact-based decision support. We could all be meteorologists as well as doctors. However, this is also the age of imagination.

Everything you need to know you can get from Google. What you cannot get is where knowledge ends. We need partnerships which do not follow straight lines but who can navigate freely; creativity not knowledge; imagination rather than intelligence. As the climate changes, our vulnerability to it and therefore our behaviour is changing, and we need to embrace this change and move away from disciplinary silos towards a multi-disciplinary, ecosystem model.

We should endeavour to embrace emotional intelligence and empathy, entrepreneurship and design, creativity and digital literacy. This guide is the start of that process. It provides the toolkit to develop and deliver impact-based forecasting and warning services and, above all, it advocates partnerships, ambition, and the desire to make a difference. It also provides a key stepping-stone to finally going the 'last mile'.

Paul Davies
Chief Meteorologist, UK Met Office

TODAY, one weather- or climate-related disaster occurs every 1-2 days – and climate change is only leading to more worrying trends in terms of frequency and scale. However the impacts of disasters are unequal, as the coping capacity of the people they hit is based on the resources at their disposal to protect themselves from disasters – often most limited in areas where climate impacts like floods, droughts and storms hit hardest. Our Red Cross and Red Crescent staff and volunteers working on the frontline know this too well.

But inequalities in front of weather- or climate-related disasters can be greatly reduced. By using forecasts and risk analyses to determine when, where, with and for whom to implement early action to protect lives and livelihoods. By applying impact-based forecasting, complex scientific information is transformed into information that is actionable, enabling humanitarian interventions such as shelter strengthening by farmers in the Philippines' coastal region before a typhoon's landfall or the distribution of veterinary kits to protect alpacas as source of livelihoods for families in the mountainous Andean region of Peru against cold wave. Existing in 192 countries as auxiliary to the government and operating from national to the community level, our local Red Cross and Red Crescent branches play a key role in bridging knowledge and practice, building trust and providing timely and relevant support developed with and for the communities.

Through the collaboration with National Hydrometeorological Services, National Disaster Management Agencies and other key stakeholders, National Red Cross and Red Crescent Societies in at least 30 disaster-prone countries across the globe are working to outsmart disasters by having pre-approved plans in place to launch forecast-based early action for extreme weather events. That number is growing. In addition, this year saw the first large-scale, coordinated inter-agency triggering of anticipatory actions by impact-based forecasts and warnings. As heavy monsoon rains hit Asia, four UN agencies and Red Cross Red Crescent partners worked alongside the Bangladesh Government to anticipate the likely impacts and release funds to help communities at risk ahead of a flood peak.

In the spirit of co-creation and collaboration, this guide has been developed to provide practical advice and promote dialogue between scientists, forecasters, disaster managers, community leaders and other relevant users. By expanding the use of impact-based forecasting, we can further strengthen our efforts to translate early warning into early action, saving countless lives and reducing suffering – efforts made more urgent than ever with our changing climate.

Pascale Meige
Director, Disasters and Climate Crisis Department
International Federation of Red Cross and Red Crescent Societies

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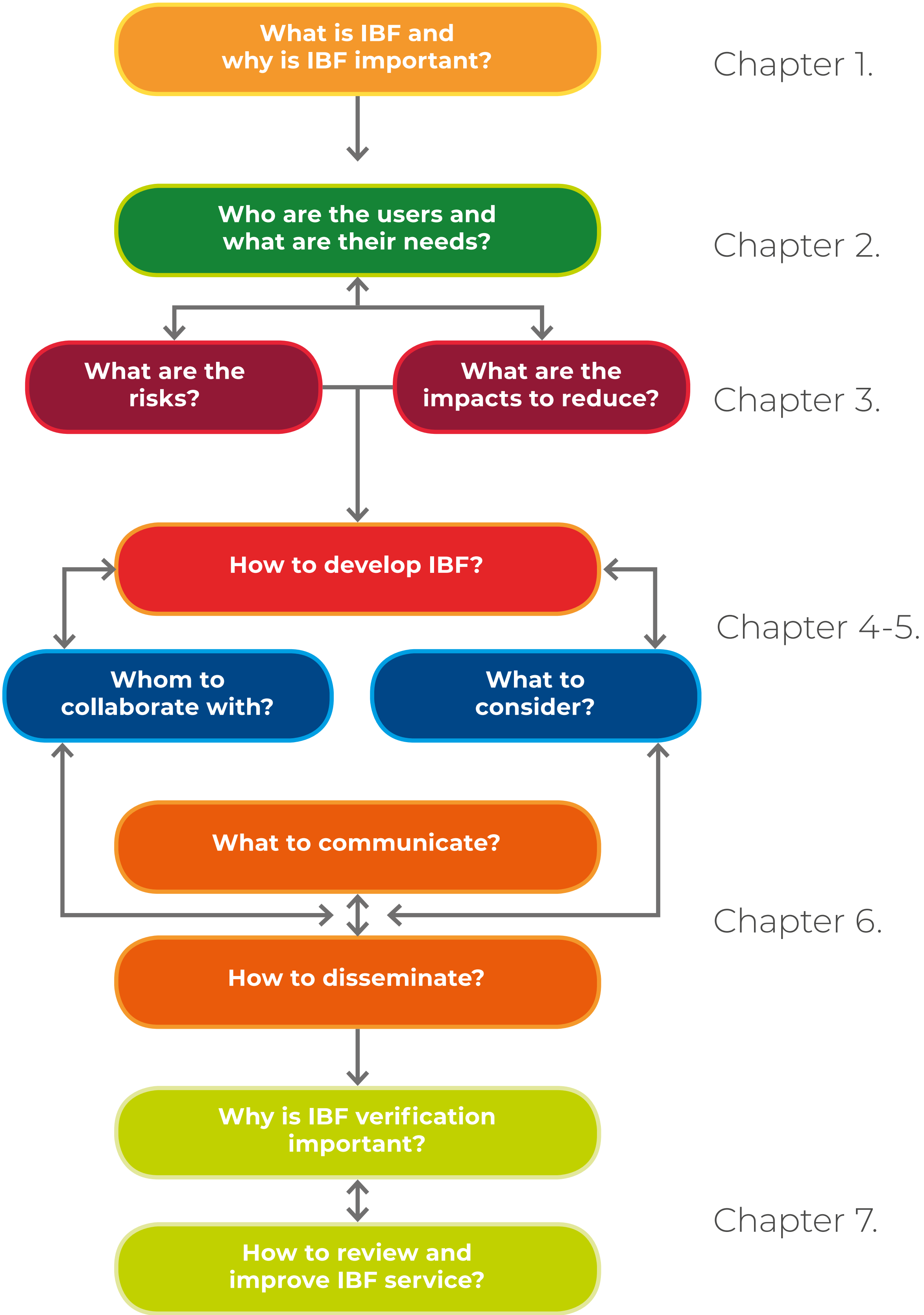
How to use this guide:

This guide outlines the steps and tools needed to develop impact-based forecasting: from understanding risk to producing, issuing and verifying fit for purpose impact-based forecasts and warnings. Designed with, and for, people working in impact-based forecasting, early warning and early action, the compiled information and recommendations will be useful for everyone from technical staff in national hydrological and meteorological services to disaster risk management, humanitarian and development agencies. The guide includes case studies from countries around the world to highlight the development and use of impact-based forecasting services for users and producers. A result of joint work between the Red Cross Red Crescent and the UK Met Office, this document aims to inspire the co-production of impact-based forecasting services that use weather, climate information, and risk analysis to reduce risk. The guide brings together the forecast-based financing methodology to trigger early action with the impact-based forecasting technical expertise of the UK Met Office and other experts in this field. Each chapter contains recommended steps and processes, as well as online resources for more detailed guidance.

Content Structure of the Guide



Chapter 1. Introduction

Cyclone Idai, Mozambique, aftermath, 15-16 March 2019
(Photo: Denis Onyodi: IFRC/DRK/Climate Centre)

Impact-based forecasting enables anticipatory actions and revolutionises responses to weather and climate crises: turning forecasts and warnings from descriptions of what the weather will be into assessments of *what the weather will be* into assessments of *what the weather will do* enables organisations and individuals across the world to anticipate and take action to mitigate the impacts brought by weather and climate events.

By developing impact-based forecasting, producers of forecasts and warnings provide critical information to help mitigate life-threatening impacts. The World Food Programme calculated that releasing funds to vulnerable communities and individuals ahead of potentially devastating weather or climate events, enables actions that save lives, livelihoods and property.

With ever growing pressure on land use, energy, livelihoods, availability of food, water and shelter, global interest in minimising human and economic cost of extreme weather and climate events continues to increase. Impact-based forecasting provides the information needed to act before disasters to minimise the socio-economic costs of weather and climate hazards. Organisations and individuals can make critical decisions to ensure that resources and supplies are in place to take early action and to respond as soon as it is safe to do so. Impact-based forecasting is one of the crucial elements of the Red Cross Red Crescent Forecast-based Financing systems. The World Food Programme calculated that releasing funds to vulnerable communities and individuals ahead of potentially devastating weather or climate events, enables actions that save lives, livelihoods, and property.

The inclusion of risk assessments makes impact-based forecasting unique among other forecasts and warnings. Hazard forecast information combined with vulnerability and exposure data is used by national hydrological and meteorological services and partner organisations to create a risk assessment.

Impact-based forecasting drives actions which save lives and protect property and livelihoods.

Impact-based forecasting provides information on the level of risk a hazard poses to a specific area.

Impact-based forecasts and warnings provide an assessment of the forecast weather or climate hazard and an assessment of the possible impacts, including when, where and how likely the impacts are.

'We found that impact-based warnings increased the likelihood that people would take protective action," says Philippe Weyrich at the Swiss Federal Institute of Technology in Zurich' The Washington Post

'Crucial evidence has been gathered to showcase the cost-effectiveness of early actions (triggered by impact-based forecasts). Across four case-studies, Return-of-Investment ratios ranged from USD 2.5-7.2 for every USD 1 spent on early interventions.' Food and Agriculture Organization. Global Dialogue Platform on FbF-Berlin 2018

'Damage, suffering and the cost of emergency aid will reduce when communities are capable of responding proactively to a disaster through early impact-based warning and early action.' Netherlands Red Cross 510 initiative.

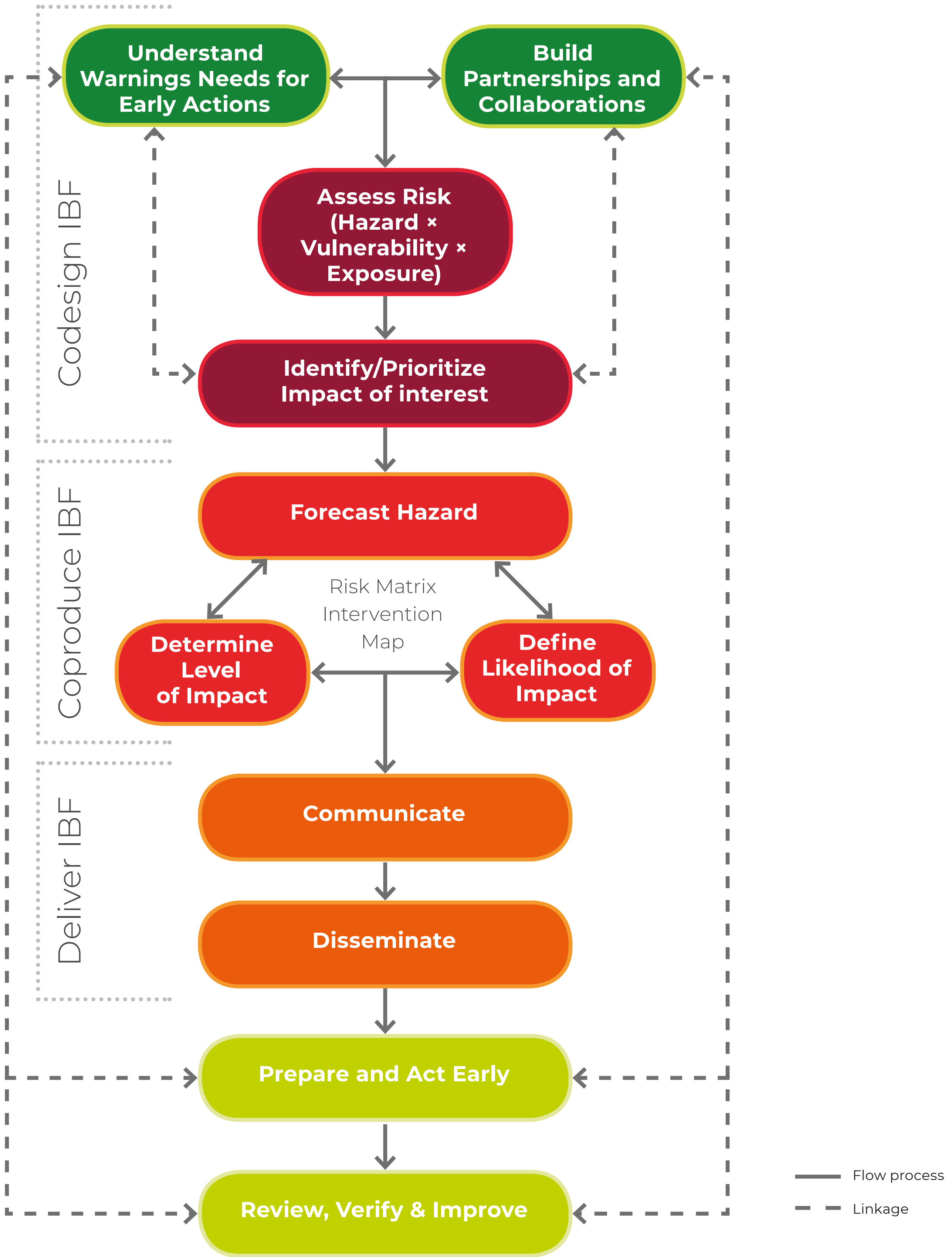
Table below contrasts fictional examples of traditional forecasts with impact-based forecasts in context of flooding and tropical cyclone.

Table 1. **Comparisons between Traditional Forecasts, Impact-based Forecasts, and Co-produced Impact-based Forecasts**

Hazard	Forecast	Impact-based forecast for Individuals/ members of public	Impact based forecast for Sector specific users
Flooding	Heavy rain is forecast. 100 to 150mm of rain is expected within a three-hour period.	Flash flooding of the County River is expected. Dwellings, farm buildings and grazing land within 30m of the river channel are expected to flood and be damaged.	The forecast water level in the recreational district is expected to cross the +0.85 alert threshold in 5 days and remain above for a further 3 days. An impact forecast of loss of household assets is over 25% and affected population over 40%.
Tropical Cyclone	A tropical cyclone category 3, windspeed of 125 km/h is expected in the next 48 hours.	A tropical cyclone category 3, windspeed of 125 km/h is expected to make landfall in 12 hours, in X and Y regions, likely to damage critical infrastructure such as bridges, blocking transport from region X to region Y.	A Tropical cyclone, lead time of 30 hours, with wind speed greater than 125 km/h, corresponding to an impact forecast of damage of 25% of housing.

With impact-based forecasting, national hydrological and meteorological services assess the impacts of the forecasted climate and weather phenomenon and consider their warnings based on the level and severity of those impacts at that particular location and /or for the target users/groups.

Methodological Framework of Impact-based Forecasting (IBF) and Warning Service



Chapter 2. Understanding Users

German Red Cross Integrated Climate Change Adaptation programme
in Teso and Karamoja sub-regions of Uganda
(Photo: Denis Onyodi/URCS-DRK-Climate Centre)

Understanding the users of forecasts and warnings is critical to the development and operational delivery of impact-based forecasting. These understandings are formed through partnerships with the individuals and organisations that will use the final tools. From the design to the delivery of impact-based forecasts and warning, input from users is essential.

Identifying users

National hydrological and meteorological services and partners developing impact-based forecasting must identify who will be using the forecasts and warnings.

Users of forecast and warnings are found often within organisations involved in disaster risk reduction, crisis management, disaster response or any organisation, business or individual that needs to make decisions in the face of a potentially impactful weather or climate event. Look for the individuals who are responsible for making critical decisions in disaster risk reduction.

Potential users of impact-based forecasts and warnings are diverse. It is not often possible to develop a forecast or warning which will satisfy all of their requirements. Often users will require impact-based forecasts and warnings services be tailored to the specific challenges they are trying to address.

Typical Impact-based Forecast Users

- Members of the public
- Community leaders
- Government departments (agriculture, social welfare, public works etc.)
- Local government officials
- Disaster Risk Reduction and Civil Protection Agencies:
  - humanitarian agencies
  - development agencies
  - police
  - military
  - hospitals and health providers
  - local disaster managers
- Local businesses
- Transport services
- Energy providers and services
- Water providers and services
- Telecommunication providers and services

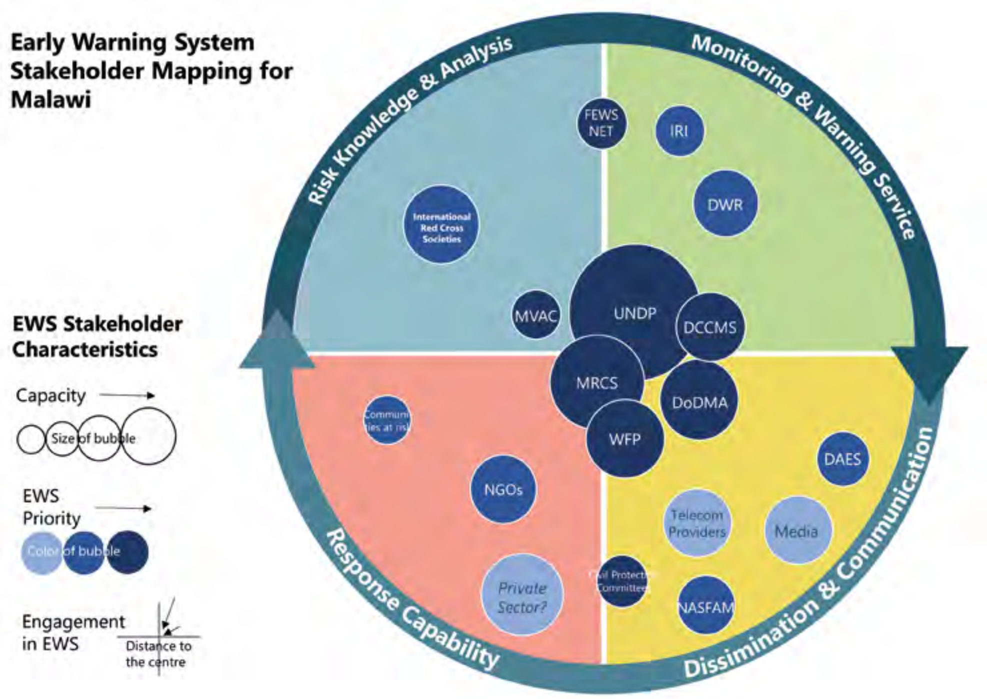
A cyclone warning would need different information to be useful to a department of public works compared to a humanitarian organisation. For a department of public works, an impact-based forecast service might focus on the probability and magnitude of cyclone hazards that are likely to severely damage certain types of infrastructure across the exposed area. A humanitarian organisation focusing on supporting the most populations will likely require information about the percentage of affected livelihoods and the percentage of potential deaths.

With such a broad and diverse range of requirements and opinions on how services should be provided, prioritising user requirements is an important step in the development process.

Analysing user needs and meeting requirements

Workshops, surveys, and interviews, among other methods, can be used to gather feedback and suggestions from potential users of forecasts and warnings. Their feedback establishes what is needed from an impact-based forecasting tool.

Figure 1. IBF Stakeholder Mapping in Malawi *(Malawi Red Cross/510 adapted for this guide by Climate Centre)*



Listed below are some sample questions to help identify users and their needs:

- Who is requesting impact-based forecasts and warnings or who could it be useful for?
- Who is using the forecasts for decision-making or to take early action?
- What forecast and warning information is currently being used?
- 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 reduce?
- How can forecasts and warnings provide appropriate information to enable informed decision-making and trigger action?
- At what spatial scale do users need forecast and warning information in order to act effectively?
- How much time do users need in order to anticipate and prepare?
- What would be the consequences of false alarms?

When processing feedback from users, the national hydrological and meteorological service and partners can assess their current forecasts and warnings on the basis of three questions:

1. **What forecasts and warnings *already exist* that can meet user requirements?**

   Users may not be aware of forecasts and warnings that already exist that may provide the level of detail they need.

2. **Which existing forecasts and warnings *can be adapted* to meet the user requirements of impact-based forecast services?**

   Some existing forecasts and warnings may need to change the way information is presented or include additional data to satisfy user needs. Converting an existing threshold-based forecast or warning into an impact-based forecast or warning may be relatively simple: needing only additional data and information from partner organisations.

   For example, where daily maximum temperature forecasts already exist, partners from health organisations or government health departments could provide relevant data on the health impacts of maximum daily temperatures. Combining and processing the two sets of information can produce an impact-based forecast for health impacts from high maximum temperatures.

3. **What *capability is needed* to produce the impact-based forecasts and warnings that will meet the user requirements?**

   Some user requirements may not be immediately deliverable without significant changes within the national hydrological and meteorological service. Organisations may need to conduct a capability assessment and/or gap analysis to identify what infrastructure, resources or datasets are needed to deliver the appropriate level of impact-based forecasting. Once gaps are identified, a diagnostic can be made of if and how those gaps can be filled.

The following chapter presents additional information on incorporating specific user requirements and risk assessments into the development of impact-based forecasting services.

Developing impact-based forecasts to address the challenges users face

The Red Cross Red Crescent uses impact-based forecasts to mitigate the impacts of extreme weather and climate for the most vulnerable populations, this is one of the key elements for decision-making for Forecast-based Financing. The specific risks and impacts addressed vary from country to country and region to region.

In a region where flooding can cause significant mortality of livestock, then the impact-based forecast may deliver an assessment of the risk to livestock.

In a region where the condition of bridges and roadways after an extreme event significantly affects the ability of organisations to deliver humanitarian aid, an impact-based forecast will need to focus on the impact to transportation networks.

The provision of timely impact-based forecasts allows for the positioning of humanitarian aid and the moving and protecting of livestock before the weather hazard occurs. Ideally, mitigating many of the challenges faced during weather and climate events.

Chapter 3. Understanding Risk and Impact

Resident of the Nolia Nua Gaon, Odisha explaining community resource and hazard maps
(Photo: Sanne Hogesteeger/Climate Centre)

IPCC Definitions of Hazard Vulnerability and Exposure

Hazard Hazard refers to the possible, future occurrences of natural or human-induced physical events that may have adverse effects on vulnerable and exposed elements. At times, hazard has been ascribed the same meaning as risk, but hazard is now widely accepted to be one component of risk and not risk itself.

Vulnerability refers to the propensity of exposed elements such as humans, their livelihoods, and assets to suffer adverse effects when impacted by hazards. The ability of a population or community to cope and adapt to disasters significantly impacts vulnerability. Coping capacity is the ability to react to, and reduce the adverse effects of experienced hazards, whereas adaptive capacity is the ability to anticipate and transform structures or organisations to better survive hazards.

Exposure refers to the presence of elements in an area in which hazard events may occur. Hence, if population and economic resources are not located in potentially dangerous settings, no problem of disaster risk exists. Exposure is a necessary, but not sufficient, determinant of risk. It is possible to be exposed but not vulnerable (for example by living in a floodplain but having sufficient means to modify building structure and behaviour to mitigate potential loss).

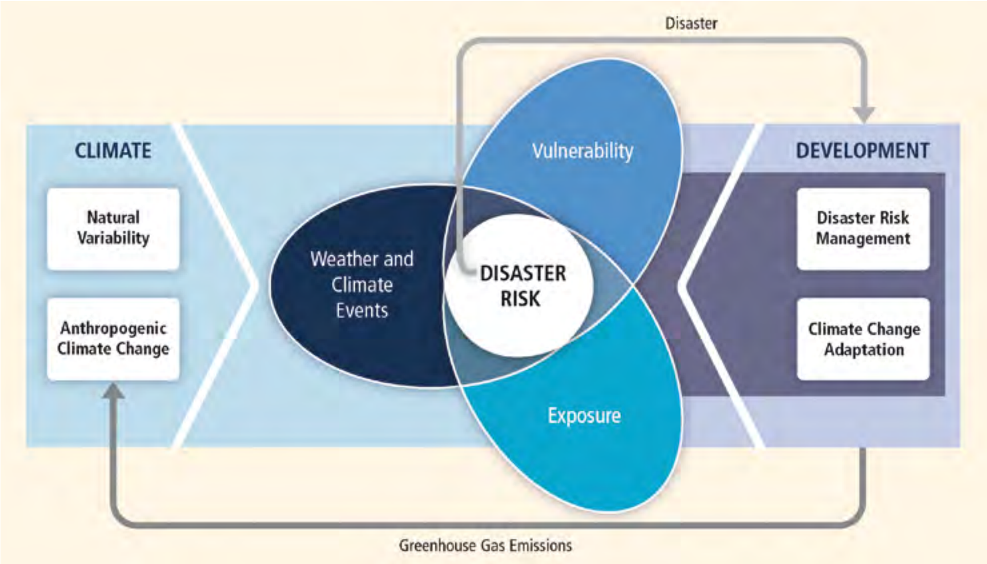


Figure 2. Schematic of the Interaction of the Physical Climate System, Exposure, and Vulnerability Producing Risk *(IPCC, 2014)*

The role of impact and risk assessments in impact-based forecasting

Risk and impact assessments are essential steps in developing impact-based forecasts and managing the risk of hazards. Well-designed risk and impact assessments can help decide what potential impacts to investigate by identifying how hazards affect people in different places.

Impact assessments turn forecasts and warnings from a description of *what the weather will be* into a message about *what the weather will do*.

A risk assessment also allows the inherent uncertainty of hydrometeorological factors to be expressed and factored into decision making. With this additional piece of information, impact-based forecasts and warnings are comprehensive and actionable over longer lead times.

Lead times for forecasts and warnings vary significantly but can be quite short, particularly ahead of extreme weather events. Impact-based forecasts, by communicating the level of certainty within forecasts and warnings, can be issued with longer lead times. While the forecast may be uncertain and the certainty in the assessment of impacts may be low, the impact-based forecast still contains valuable information long before the forecasted hazard. For example, instead of waiting to determine a potential flood location with 90% confidence to issue a flood alert, a hydrological and meteorological service might issue an impact-based forecast showing low likelihood of flooding over a larger area 5 days in advance, and then narrow down the region to show high likelihood and high impact at a 24 hours lead-time.

Impact assessments: identifying hazard impacts

For impact-based forecasts and warnings it is important to identify the specific impacts of a given hazard. Different approaches, methodologies and tools are used to collect impact data, but the typical impacts expected of any given hazard are well understood, especially when historical information is available. Table 1 highlights potential sources of information and datasets for identifying hazard impacts.

Table 2. Potential Data Sources for Hazard Impacts

Hazard impact data sources		
Hazard	**Impact**	**Data Repositories**
▸ National and regional hydrological and meteorological services ▸ World Meteorological Organization catalogue of extreme weather events ▸ Research institutes (e.g. Dartmouth Flood Observatory, UNEP, Copernicus, International Research Institute IRI, FloodList)	▸ *Primary data providers* - Government ministries (environment, social welfare, health, public works, energy) water; Civil Protection Agencies/National Disaster Management Authorities ▸ *Humanitarian sector* - Affected communities, traditional knowledge holders, practitioners ▸ *Media* - newspapers, social media	▸ *Data repositories* - (e.g. EM-Dat, Desinventar, Preventionweb) ▸ *Data collection methods*: Rapid damage assessments, Post Disasters Needs Assessments

In gathering historical datasets for a hazard, the following key questions may be helpful:

- What were the impacts?
- When did the impacts occur?
- Where were the impacts observed?
- What is the quality of the historical records?
- What was the magnitude of the hazard? This can be related to the return period.
- What is the frequency and geographic distribution of impacts from a particular hazard?
- How is the nature of the hazard expected to change in the future due to climate change, climate variability, socio-economic changes and other external drivers?

While it may be challenging to develop an impact database with sufficient quality in terms of spatial and temporal resolution, even in data sparse regions, impact-based forecasting can still be produced. This is explored in more detail in ***Chapter 5. Producing Impact-based Forecasts and Warnings***.

Flash flood from Lake Albert in Uganda, May 2020
Photo: Red Cross Climate Centre

Table 3. Examples of Disaster Impacts

Hydrometeorological Hazard	Cascading hazards	Primary impacts	Secondary impacts
Heavy Rain	▸ Landslide ▸ Excessive erosion ▸ Flooding (flash flood, river flood, waterlogging) ▸ Mudslide ▸ Silt deposit	▸ Damage of properties, infrastructure ▸ Damage to certain crops and loss of livestock ▸ Death by drowning ▸ Damage to topsoil ▸ Damage of properties, buildings, infrastructure ▸ Damage certain crops, especially tubers ▸ Dangerous travelling conditions	▸ Houses inhabitable ▸ Loss of services: power, water, communications, health care ▸ Health issues/deaths: waterborne diseases etc ▸ Loss of livelihood ▸ Loss of industrial production ▸ Displacement/Migration: long and short term
Wind	▸ High waves	▸ Danger to life from flying debris ▸ Damage to properties, buildings and other manmade structures ▸ Trees, forests and orchards damaged or uprooted ▸ Destroys some standing crops, especially basic grains ▸ Dangerous travelling conditions ▸ Dangerous sea states ▸ Damage and disruption to transport networks (trees on railway lines and roads, ferry ports inaccessible)	▸ Loss of services: power, water, communications ▸ Loss of livelihoods ▸ Injuries ▸ Houses inhabitable
Snow	▸ Snow drift ▸ Avalanche	▸ Transport networks inoperable ▸ Damage to property from weight of snow ▸ Grazing inaccessible ▸ Crop damage ▸ Deaths	▸ Loss of livestock ▸ Loss of services: power, water, communications ▸ Loss of livelihood ▸ Access to health care, education, food and medical supplies ▸ Loss of industrial production ▸ Road traffic collisions
Ice	▸ Ice accretion on cables	▸ Damage to power lines ▸ Power outages ▸ Transport networks inoperable ▸ Damage to crops	▸ Road traffic collisions ▸ Loss of services: power, water, communications ▸ Access to health care, education, food and medical supplies

Hydrometeorological Hazard	Cascading hazards	Primary impacts	Secondary impacts
Lightning		▸ Danger to life ▸ Damage to property ▸ Power outages ▸ Delays to rail and air travel	▸ Loss of services: power, communications
Hail		▸ Damage to property ▸ Danger to life ▸ Dangerous driving conditions ▸ Damage to and loss of crops and livestock	▸ Loss of livelihood
Low rainfall	▸ Drought[1] ▸ Dust storms ▸ Desertification	▸ Severe crop losses ▸ Water shortages	▸ Loss of livelihood ▸ Loss of livestock ▸ Soil erosion ▸ Food shortages ▸ Increased hunger and malnutrition ▸ Disease (e.g. measles and diarrhoea) ▸ Displacement/Migration: long and short term ▸ Conflict
High temperatures	▸ Heatwave	▸ Danger to human and livestock health ▸ Power outages ▸ Interruptions to public transport (rail)	▸ High temperatures exacerbate existing health conditions ▸ Death
Low temperatures	▸ Cold wave	▸ Danger to human and livestock health ▸ Damage to and loss of crops	▸ Low temperatures exacerbate existing health conditions ▸ Death
Coastal/storm surge	▸ Rapid flooding ▸ Removes topsoil and increases salinity	▸ Danger to life ▸ Damage to infrastructure including settlements, property, transport, power networks ▸ Destroys most crops ▸ Disrupts and contaminates water supply	▸ Displacement ▸ Loss of services: power, water, communications, health care ▸ Health issues: waterborne diseases etc ▸ Loss of livelihood
Fog	▸ Reduced visibility	▸ Disruption to transport networks ▸ Damage to and loss of crops (humidity). ▸ Delays to air travel	▸ Loss of livelihood

[1] This guide recognises that there are several other factors that increase the risk of droughts.

Risk Assessments

Risk assessments are the keystone of impact-based forecasting and require information on the following dimensions:

- Hazard
- Exposure
- Vulnerability (including coping and adaptive capacity)

Defining Risk

Risk assessments should include individual analysis of risk factors alongside, and informed, by the historical impact assessment for each hazard of interest. The impact assessment can focus and guide the data collection and collation on risk dimensions like vulnerability, exposure and coping capacity. For example, in an event where a primary concern is housing damage from strong winds, hazard data on historical wind speeds and vulnerability data on housing quality is required. During the risk and impact assessments, working with partner organisations and users to identify the risk indicators that drive impacts will improve both processes.

In many cases, risk assessments use a combination of objective and subjective methods. Consequently, data on different risk dimensions often begins as qualitative and develops iteratively. As more data and feedback from users and partners is made available, the assessments become more quantitative. Producing an objective assessment of risk will be challenging due to factors that affect the quality and robustness of information used throughout the process, including: how data is collated; what data is available; how data is processed; what assumptions have been made in weather and climate models.

Common global Geospatial Platforms for vulnerability and exposure data

ThinkHazard! (GFDRR)

OpenStreetMap

INFORM

The Humanitarian Data Exchange (UN OCHA)

GeoNode

Identifying the hazard

When resources are limited, prioritize impact-based forecasting for hazards with the greatest impact and risk. Selecting the appropriate hazard is essential to developing a risk assessment and ultimately developing an impact-based forecast. The decision should be based on a combination of the following:

- The extent to which a hazard will cause negative impacts on lives, livelihoods, well-being and other developmental aspects
- The forecast skill available
- The forecast lead time: the length of time between the issuance of a forecast and the onset of the disaster.

Hazards that have been bringing significant impacts to the people and economy should be selected for the impact-based forecasting service. However, where there is insufficient modelling capability and forecasting skill, hazards may need to be excluded from impact-based forecasting, even though the impact brought by the hazard can be significant. Also important is to ensure that the lead time available for the hazard can provide sufficient time to implement early actions and mitigate impacts in advance.

Observed hydrometeorological conditions and weather or climate model output are used to produce a weather or climate hazard forecast. Ensemble forecasting establishes the probability of the weather or climate hazard occurring. The resulting hazard forecast is used as the basis to calculate the level of impact and the likelihood of impacts occurring.

In order to better understand hazards at a spatial scale, hazard exposure should be obtained in the risk assessment phase (for example, see UNEP flood exposure). This exposure represents an average, or typical, likelihood that an area will be affected by a certain hazard. For example, a hydrological model can be used to determine flood extent for a certain return period or observed flood extents can be averaged by analysing remote sensing data over a set period. To determine hazard exposure, data is combined with exposed population datasets, such as in the calculations of UNEP.

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 snowfall as example, this would refer to snow depth with a 20% probability of being exceeded in any given year. 5-year events can occur in the same year, consecutive years, or several years apart. The World Meteorological Organization outlines statistical methods that can be used with historical data, to generate return periods in Comprehensive Risk Assessment for Natural Hazards.

Vulnerability and Exposure

Vulnerability and exposure data, or indicators, are required to provide an objective assessment of risk in impact-based forecasting. Organisations that manage datasets with this type of information will be ideal candidates for impact-based forecasting partnerships.

To identify the relevant vulnerability and exposure datasets needed for impact-based forecasting, it is important to know what problems or issues the impact-based forecasts and warnings are trying to address. For example, if the information in a forecast will be used to take early action to reduce flood damage to housing, the exposure and vulnerability indicators must be specific to the characteristics that indicate the robustness or build quality of houses, when data is not available proxy indicators can be used.

Going beyond hazard forecasting towards impact-based forecasting requires linking forecasts with vulnerability and exposure data. Essential data includes an archive of disaster impacts, in order to assess the relationship between the hazard and impact [to build 'stage-damage curves']

(Ward et al., 2013)

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 livelihoods are affected?
- Which sectors are affected the most?

Key Data Questions

The Red Cross Red Crescent recommends considering the following key questions when identifying vulnerability and exposure data:

Exposure

- Which populations, infrastructure, natural resources, or assets are exposed?
- Where are they? For example, households on the wrong side of protective embankments or in river basins a long way from high ground are particularly exposed.

Vulnerability

- What are the vulnerability indicators that are related to the identified impacts?
- How are impacts related to the underlying causes of vulnerability? For example, people with houses made from low-quality materials will be vulnerable to damage. However, more indirect vulnerabilities such as poverty and literacy might play a role an individual's ability to prepare for and cope with impact.

Data Quality

- What is the quality and availability of data for vulnerability indicators? How often are they updated?
- Which vulnerability indicators may be redundant (e.g. education levels and literacy), and which indicators provide new information? Once the vulnerability and exposure indicators are defined, a composite updatable vulnerability index can be developed as one layer of the impact-based forecasting model. If you are developing a composite index, be careful about which contributing layers you select, so as not to overweight certain patterns of vulnerability.

Once such indicators are established, authoritative, credible sources of data from partners and collaborating organisations should be the first choice for vulnerability and exposure data. This ensures access to the most relevant data and allows partners to discuss and identify the datasets needed for impact-based forecasting.

Vulnerability and exposure data can be obtainabed from global platforms (including geospatial) and national level databases, such as national statistics and disaster risk management agencies. Local organisations, such as district office and municipal town halls, can help identify and access subnational and local level databases.

However, ensuring that vulnerability and exposure data is of high quality, available in a timely manner, and is inclusive can be challenging:

- *Vulnerability and exposure changes over time, particularly after an extreme weather or climate event.* Datasets must be kept up to date to ensure the impact-based forecast or warning using this data is reliable. Recognise that many official governmental data sources, such as a national census or demographic and health surveys, are updated infrequently – every five or ten years.

- *Data is sometimes available only at a more aggregated level.* Granular information is frequently only partly digitised or not available at a nation-wide level, and therefore more difficult to use. For example, data gathered by non-governmental organisations and the humanitarian sector through Vulnerability and Capacity Assessments are typically available at the much lower administrative level (town or village).

- *Datasets can contain biases.* Using crowd-sourced derived data, such as from social media, comes with the risk that poor and vulnerable communities are often not represented in these data streams due to the digital divide. However, official statistics might not cover informal settlements or vulnerabilities linked to informal economies" (van den Homberg 2018) and crowd-sourced data that includes these communities may provide valuable information.

Once vulnerability and exposure data are gathered and processed, the data can be analysed alongside the hazard information to produce a risk assessment. Commonly, this is done using a composite risk index, such as the EU JRC does with the INFORM Index. Equal weight is given to all of the indicators under the main risk dimensions of hazard, exposure and vulnerability (including coping capacity).

Case study UK Met Office Wind Warnings

For the far north-west of the UK, strong winds are a way of life. In this region, much higher wind speeds are needed to cause similar level of impact than lower windspeeds in the rest of the country. There are no significant bridges, no railways and very few trees. The impacts of greatest concern are generally structural damage, public safety, power/telecoms outages, and safety on coasts/causeways from high seas.

Table 4. Winter Windspeeds and Impact levels

Winter		
Wind gust speed (mph) south of UK	Wind speed gust (mph) north west of UK	Indicative Impact Level
60-70	70-80	Low
70-80	80-90	Medium
80+	90+	High

For all UK weather warnings, thresholds are only used to inform the risk assessment where there is a correlation between the specific hazard threshold and impact. The risk assessment for a particular event then makes the use of these indicative thresholds, but then an adjustment is usually applied based on changes in vulnerability and exposure across the warning area.

In the summer, two additional factors affect the thresholds used for wind warnings: trees are in full leaf, making them more susceptible to wind damage, and more people are spending time outside, with a large increase in the number of people holidaying in tents, caravans and mobile homes. The thresholds used for wind warnings in the summer are therefore lower than in winter, with low impact warnings potentially being issued across southern parts of the UK for wind speeds starting at 50mph.

Identifying impact levels from hazard thresholds

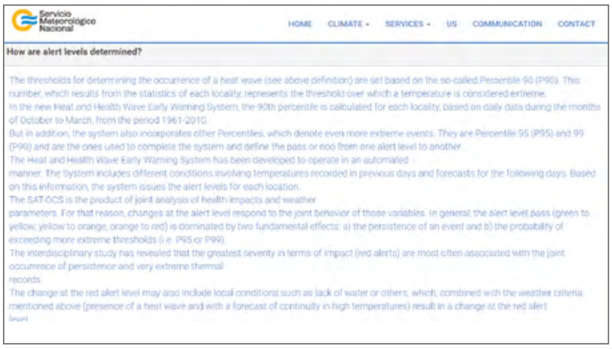
Hazard-based forecasts and warnings often use hydrometeorological thresholds based on the magnitude of the hazard as the trigger to issue a specific forecast or warning. Although thresholds do not need to be explicitly communicated within impact-based forecasting (unless requested by the user), hydrometeorological thresholds are important within the impact-based forecasting process. Identifying an appropriate hazard threshold beyond which impacts are possible, or the level of impact is unacceptable, 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. The hazard's magnitude may then be used as a proxy for the level of impact, taking into consideration that thresholds might only be useful proxies in certain contexts or for specific locations. For example, the UK Met Office uses wind gust speed thresholds as an initial proxy for impacts in windstorms (see box above). Many hazards have multiple thresholds at which impacts occur. Thresholds will vary based on area affected, topography, antecedent 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. Additionally, thresholds may need to be reconsidered after an event occurs, especially for hazards that can occur in close succession, as the vulnerability and exposure can change as a result of the preceding event.

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 minimise the impacts. For example, in Argentina, temperature thresholds have been developed in conjunction with the Ministry of Health and other partners, which are used for impact-based heat wave warnings.

Case study Identifying thresholds for heatwave warnings in Argentina

From summer 2017-2018, the Early Warning System of Heat Waves and Health (SAT-OCS) was implemented in the *Servicio Meteorológico Nacional*, the National Meteorological Service of Argentina. Available from October to March, the Early Warning System works automatically for 57 localities in the country, issuing a daily alert.



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How are alert levels determined?

The thresholds for determining the occurrence of a heat wave (see above definition) are set based on the so-called Percentile 90 (P90). This number, which results from the statistics of each locality, represents the threshold over which a temperature is considered extreme.
In the new Heat and Health Wave Early Warning System, the 90th percentile is calculated for each locality, based on daily data during the months of October to March, from the period 1961-2010.
But in addition, the system also incorporates other Percentiles, which denote even more extreme events. They are Percentile 95 (P95) and 99 (P99) and are the ones used to complete the system and define the pass or noo from one alert level to another.
The Heat and Health Wave Early Warning System has been developed to operate in an automated manner. The System includes different conditions involving temperatures recorded in previous days and forecasts for the following days. Based on this information, the system issues the alert levels for each location.
The SAT-OCS is the product of joint analysis of health impacts and weather parameters. For that reason, changes at the alert level respond to the joint behavior of those variables. In general, the alert level pass (green to yellow, yellow to orange, orange to red) is dominated by two fundamental effects: a) the persistence of an event and b) the probability of exceeding more extreme thresholds (i.e. P95 or P99).
The interdisciplinary study has revealed that the greatest severity in terms of impact (red alerts) are most often associated with the joint occurrence of persistence and very extreme thermal records.
The change at the red alert level may also include local conditions such as lack of water or others, which, combined with the weather criteria mentioned above (presence of a heat wave and with a forecast of continuity in high temperatures) result in a change at the red alert level.

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What are the recommendations for a heat wave?

Recommendations are indicated by health agencies. We review some of them below and suggest referring to official information:

http://www.msal.gob.ar/salud-y-desastres/index.php/informacion-para-ciudadanos/cuidados-de-la-salud/ola-de-calor
https://www.argentina.gob.ar/salud/glosario/golpedecalor To avoid the effects of intense heat it is recommended:

- Increase fluid intake without waiting to be thirsty for proper hydration.
- Do not expose yourself to the sun excessively, or at central times of the day (between 11 and 17 hours).
- Avoid alcoholic or highly sugary beverages.
- Avoid very hearty meals;
- Ingest vegetables and fruits.
- Reduce physical activity
- Wear light, loose-fitting, light-colored clothing; hat, dark glasses.
- Stay in ventilated or airy spaces.
- Remember that there is no drug treatment against HeatStroke and only the classic methods cited above, can prevent and counteract it.
- Faced with a headache, vertigo, nausea, confusion, seizures and loss of consciousness; red, hot and dry skin; breathing and weak pulse, and high body temperature (between 41 and 42 degrees Celsius), should be acted as follows:
  - Move the affected in the shade, to a cool and quiet place. Make him keep his head a little high.
  - Try to refresh it, wet your clothes, apply ice to your head, give it fresh or slightly salty water, and ask for medical help.

Figure 3. Web site description of how heatwave thresholds are calculated and Advice on what to do in a heat wave to minimise impact on human health (translated from the original Spanish)

At each level of alert, the population and civil protection organizations can take appropriate prevention, mitigation and response measure. In addition to displaying heat wave alerts, the website also communicates what a heat wave is, how the alert levels have been determined and what to do in a heat wave to reduce the impact on human health.

A more comprehensive description of the methodology used to determine alert levels is available in Spanish here.

Future hazards and impact levels

Climate change has the potential to bring unprecedented hazards and levels of impact. Consideration of potential future events and the impacts that may occur should be incorporated into the development of impact-based forecasting. This means impact-based forecasting models should be updated regularly. For example, if using a machine learning algorithm, retraining the algorithm as new data becomes available is recommended. Here new advances in data science such as streaming data could enable near-automatic retraining.

Manuela di Mauro recommends building on past event data but taking into account future events in Quantifying Risk Before Disasters Occur: Hazard Information for Probabilistic Risk Assessment. Such an approach provides better coverage of the possible events and results in an improved estimation of the probability of occurrence of each event and associated impacts. Mauro also outlines appropriate equations to apply to hazard, vulnerability and exposure data to produce a probabilistic risk assessment for natural hazards, which can be applied to impact-based forecasting.

Chapter 4. Partnerships and collaboration

ARRCC Stakeholder Consultation Workshop in Bangladesh
Photo: RIMES/UK Met Office

Developing an impact-based forecasting service requires partnerships and collaboration. Partner organisations can help identify the impacts that are of most concern, assess user requirements, and understand the hazards that drive those impacts. A strong collaborative approach brings together the producers of weather, climate and risk information with those who use the information to make decisions.

A variety of methods can be used to gather, analyse and develop user requirements, such as workshops, surveys, interviews, and technical working groups to analyse and develop requirements into impact-based forecasting.

Getting those workshop formats, and survey and interview questions right requires expertise as well as significant time and resources. Working with partners to co-design, deliver and analyse the outcomes is recommended. Through such a co-creation process, partners contribute their expertise and insights –strengthening the learning design and process.

If needed, additional external facilitators and market research experts, supported by partner organisations, can frame the questions that need to be asked and the techniques that can be used to gather information from users.

Figure 4. Future Climate for Africa: Six Building Blocks for Co-production

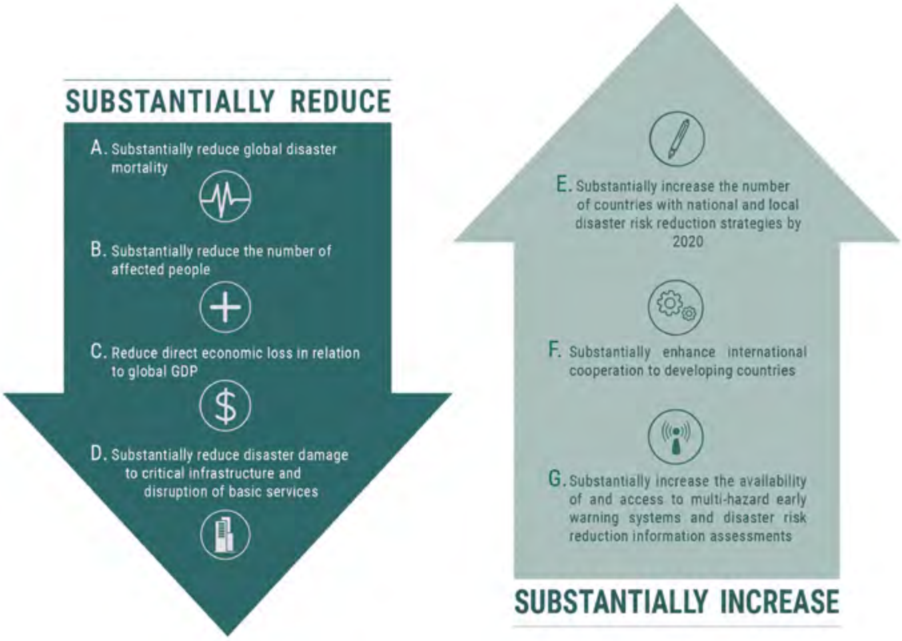
Highlight Lake Victoria WISER HIGHWAY Project

Lake Victoria supports Africa's largest inland fishery. Annually, the fishery produces approximately 1,000,000 tons of fish, employs about 200,000 fishers, and generates over 500 million USD in exports. Over 30 million people live near the coastline near 1,400 landing sites or beaches from which 50,000 boats operate. Through the WISER HIGHWAY project (HIGH impact Weather lAke sYstem), a partnership among the national hydrological and meteorological services and stakeholders from Kenya, Rwanda, Tanzania and Uganda coordinates early warning services for the Lake and its basin, with potentially one centralised operational centre to provide impact-based forecasts of storm events to fisherman and small boat operators.

Partnership benefits continue even after development and implementation of impact-based forecasting services. Members of the partnership can be tasked with monitoring the effectiveness of forecasts and warnings and providing feedback for improvement.

Partners are also critical in communicating impact-based forecast and warnings. Some partner organisations will have responsibilities for anticipatory actions: to prepare for and respond to weather and climate events. These actions likely include providing advice to vulnerable communities on what to do in an extreme weather or climate event. Combining partner's anticipatory advice with impact-based forecasts and warning can provide a seamless forecast and advice service to users.

Figure 5. United Nations Office for Disaster Risk Reduction: Seven Targets of the Sendai Framework for Disaster Risk Reduction 2015-2030



Partnerships and collaboration in impact-based forecasting align with several global frameworks, such as the International Network for Multi-Hazard Early Warning System (IN-MHEWS), the Climate Risk and Early Warning Systems initiative (CREWS), and the Sendai Framework for Disaster Risk Reduction. In particular, developing impact-based forecasting contributes to five of the seven Sendai Framework targets (A, B, C, F, G).

Roles and responsibilities of partner organisations

The roles, responsibilities and the level of collaboration required from each organisation within impact-based forecasting will vary. The World Meteorological Organization provides some overall guidance on how to set up Memorandums of Understanding between partner organisations and what to consider when establishing partnerships.

Some organisations may already have official roles relevant to impact-based forecasting. The World Meteorological Organization Alerting Authorities list designates which organisations are recognised by a member state to issue official alerts. Other organisations may need roles and responsibilities formalised. However, if an organisation does not already have such a mandate, establishing formal agreements that clearly outline the roles and responsibilities of each organisation joining a partnership may be necessary.

Vietnam Forecast based Financing Project for Heatwaves

In Hanoi the average daily temperatures have risen in recent years. Preliminary analysis also indicates that past heatwaves have led to a 20.0% increase in hospital admissions for all causes and 45.9% for respiratory diseases.

The Vietnam Red Cross, German Red Cross, the Vietnam Institute of Meteorology, Hydrology and Climate change (IMHEN), and Columbia University's International Research Institute for Climate and Society co-designed a plan and developed impact-based forecasting for heatwaves in Hanoi.

This partnership made the development of an impact-based forecast service possible and inspired other national hydrological and meteorological services to follow suit. The service, used by the Vietnam Red Cross Society, triggers early actions prior to heatwave shock. Early actions include setting up cooling centres for outdoor workers and other vulnerable people, distributing drinking water, and raising awareness around heat strokes symptoms and when and where to get medical assistance.

Challenges and opportunities for creating flourishing partnerships

When developing partnerships and collaborations, challenges to successful implementation are common. Here are a few of those potential challenges with new partners or collaborators:

- Lack of knowledge about what impact-based forecasting is
- Does not recognize impact-based forecasting's added value for early action
- Lack of incentives (including financial resources) to move towards impact-based forecasting
- Limited capacity of forecast service providers with the knowledge and skills needed for the development of impact-based forecasting services
- Potential partners (for example government agencies) operate under different ministries
- Lack of clarity on whose mandate it is to develop and issue impact-based forecasts

These challenges can be addressed when existing and future hydro-met capacity building and early warning and early action investments are developed in a coherent way, incentivising the joint development of capabilities towards impact-based forecasting and anticipatory action. Advocacy at all levels of government, nationally and internationally create the political environment to support effective partnership towards sustainable impact-based forecasting services.

Forums like the Regional and National Climate Outlook Forums (COFs) offer the opportunity to build strong partnerships by bringing together NMHSs with sector experts and a variety of users. Networking and discussion at the COFs and other relevant platforms and events can help identify needs and structure participation, with contributions from all involved.

Table 5. Uganda Action-based Flood Forecasting Project: Organisations and Roles - Example

Organisation	Role
Uganda National Meteorological Authority	Provision of rainfall forecasts Co-develop the trigger thresholds for Forecast-based Financing Conduct feasibility of GloFAS for Uganda
Directorate of Water Resources Management (under Ministry of Water and Environment)	Feasibility of GloFAS for Uganda Participation in trigger development Provision of riverine data Create linkages with planned government Flood Modelling Centre
Office of the Prime Minister	Provision of data
Uganda Red Cross Society	Co-development of the trigger Pilot the trigger and
Red Cross Red Crescent Climate Centre	Technical support towards development of impact-based forecasting
Netherlands Red Cross - 510	Technical support towards development of impact-based forecasting (mainly supporting access to and analysis of data needs for impact-based forecasting, modelling)
University of Reading	Support access to and feasibility of GloFAS for Uganda
European Centre for Medium Range Weather Forecasts (ECMWF)	Operational delivery of GloFAS Provision of hydrometeorological data Development of auto-alert system, activating when trigger is crossed

Case Study The Natural Hazards Partnership (UK)

The Natural Hazards Partnership leads the way in moving from a hazard-based to an impact-based approach. The Partnership formed in 2011 to share expertise and best practices in the development and delivery of natural hazard forecasts, warnings and services. It is a consortium of 19 public bodies, mainly government departments and agencies, trading funds and public sector research establishments.

Through extensive collaboration within the Partnership, the diversity of scientific expertise allows for analysis of highly complex natural hazards and the socio-economic factors which affect likelihood and level of impacts. Collaboration also enables the Partnership to work efficiently to produce scientifically robust and practically relevant models and information for emergency response.

The aims of the Natural Hazard Partnership are:

- Establish a forum for the exchange of knowledge, ideas, expertise, intelligence and best practice in relation to natural hazards
- Provide a timely, common and consistent source of advice to government and emergency responders for civil contingencies and disaster response
- Create an environment for the development of new services to assist in disaster response

Figure 6. Organisations Involved in UK's Natural Hazard Partnership

The Natural Hazard Partnership is underpinned by a Memorandum of Understanding (MoU) between the partners. The MoU sets out the basic principles of collaboration and also maintains an operating plan that clearly defines the agreed priorities, activities and structures of the partnership.

To do all this, the Natural Hazard Partnership overcame a number of collaborative challenges, including bringing multiple organisations from across the country together, by building common ground, respect and trust. This has allowed the development of strong leadership and inter-organisational coordination practices and created an agreed common approach to scientific research. These achievements have helped to ensure that the Natural Hazard Partnership produces valuable products, services and advice. Some of the products and services developed by the Natural Hazards Partnerships:

- Daily Hazard Assessment - *An overview of 12 potential natural hazards and health implications that could affect the UK over the next 5 days, including: weather, flooding, volcanic ash, space weather, landslide, wildfire, hot and cold temperatures, air quality and aero allergens. Provides a hazards summary to help increase UK's ability to respond to and be prepared for multi-hazard events.*
- UK Government National Risk Assessment - *Identification of potential natural hazards for inclusion and assessment. Coordination of partnership constituent organisations and agencies to support lead government departments in developing robust 'reasonable worst-case scenarios' for natural hazards. Provision of expertise to deliver an independent review of the natural hazard risks within the National Risk Assessment.*
- Science Notes - *The Natural Hazards Partnership produced a series of Science Notes. These notes are short, introductive guides to each natural hazard. Key aspects are highlighted, that may need to be considered in decision-making during an emergency involving this hazard.*

Chapter 5. Producing Impact-based Forecasts and Warnings

Alex Burkill of UK Met Office on Weather Forecasting Desk
Photo: UK Met Office

Impact-based forecast and warning production relies on a wide range of resources and capabilities. This chapter outlines the steps and considerations for producing and operationalising impact-based forecasts products and tools.

Choosing a hazard - start simple

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 conflicting user requirements. National hydrological and meteorological services and partner organisations should work with users to determine which hazard to prioritise.

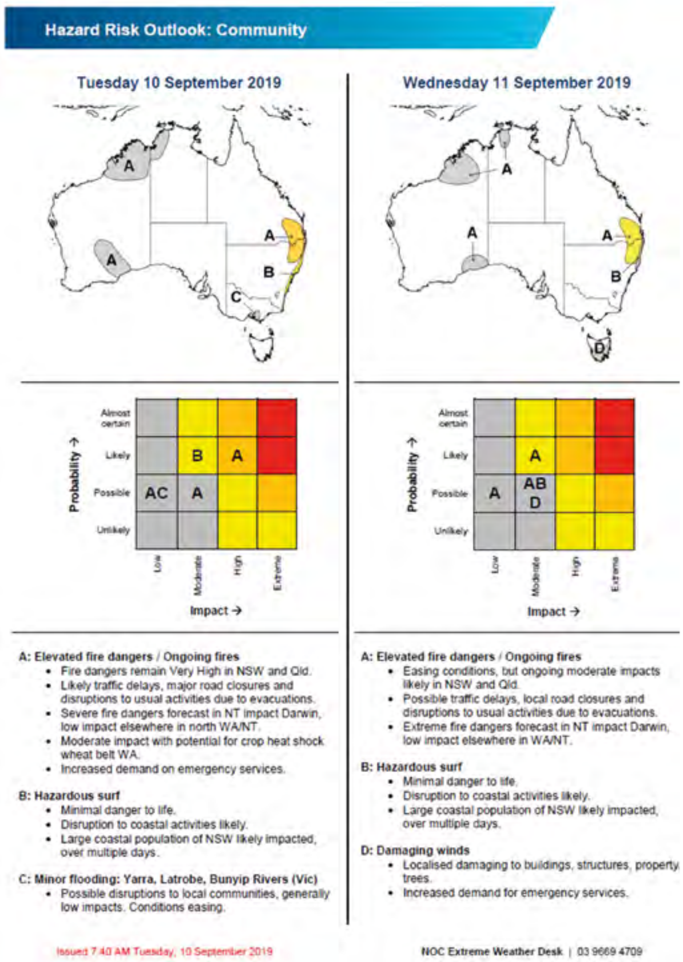
Hazards may operate on different timescales, such as a seasonal timescale (severe wet season, severe winter, extended heat wave), a monthly timescale (severe wet period, cold, hot period), a weekly timescale (typhoons, hurricanes), a daily timescale (thunderstorm) or a short notice/nowcast timescale (flash flooding). Regardless, the methodology for producing impact-based forecasting is the same.

In some cases, availability of data and geographical context will be a deciding factor in hazard and location selection. For example, if the hazard of interest is flooding, the river catchment or tributary, with some available data and where flooding is known to cause significant impacts should be chosen.

Users' greatest concerns may be linked to multi-hazard situations, such as cyclones. In these cases, breaking multi-hazards down into constituent hazards makes the task more manageable. For example, in Bangladesh and the Philippines, wind hazards are one element of concern during cyclones. In these locations, impact-based forecasting specifically for wind hazards associated with cyclones already enable mitigation of impacts.

In Australia, the Bureau of Meteorology created the National Hazard Outlook. The Outlook uses an Impact-probability-based matrix (also referred to as a risk matrix) to produce a nationwide graphical outlook product that indicates potential hotspot regions for weather phenomenon and their likely impact level. Australia has seven states and territories, all with different sets of user requirements. The Bureau of Meteorology recognised that developing impact-based forecasts for each state required significant resources. Developing an impact-based National Hazard Outlook, however, was feasible. Because the Outlook could build upon existing thresholds used for warnings and had demands from users, production did not require the kind of expensive paradigm shift that can occur when moving from hazard to impact forecasting.

Figure 7. Impact-based National Hazard Outlook in Australia



Determining the level of impact

In existing impact-based forecasts and warnings, calculating the level of impact requires combining information from modelling, past events, and risk analysis (see ***Chapter 3. Understanding Risk and Impact***).

Modelling combines forecast hazard magnitude with vulnerability and exposure data to determine the potential severity of the impact. Hazard impact curves, which compare the magnitude of hazard against specific impacts, can also be used to identify if forecast hazards will result in impacts.

Past event analysis correlates information from past events to the magnitude of the hazards which occurred during the same event. For forecast events, these correlations are used to provide an estimate of potential impact. Estimates of impact are also adjusted based on known population vulnerability and exposure information within the forecast area.

The Red Cross and Red Crescent National Societies and their partners use the analysis of past events to develop impact-based forecasting for Forecast-based Financing pilot projects. In Uganda, impact-based forecasting for river flooding was developed using historical newspaper records and disaster records of previous floods. The team identified the river levels associated with flooding in each area and used this information to forecast impacts. In Bangladesh, the team investigated cyclone winds, using a small sample size, to identify the wind speeds at which impacts occurred.

In both cases, a lack of comprehensive disaster datasets did not prevent the development of impact-based forecasts and warnings. The smaller sample sizes and qualitative nature of some of the data analysis does lower the overall certainty in the forecast, which is reflected in the risk assessment within the impact-based forecast.

A lack of data, from observation networks, modelling or socio-economic datasets, does not mean that impact-based forecasting is not possible. 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.

Determining likelihood of impact

Likelihood of impact is an important tool for decision-makers. Providing an assessment of likelihood of impact enables organisations that activate before a weather or climate event occurs to assess the socio-economic costs and benefits associated with acting early against the cost of doing nothing. To establish how likely impacts are, both the uncertainties in the hydrometeorological forecast and the uncertainties in vulnerability and exposure data need to be considered.

Forecast Verification

Without verification, forecast results cannot be considered trustworthy. In order to develop and trigger actions based on a forecast, responders must know if the forecast provides accurate information on the likelihood of an event and its impacts.

Ideally, forecast verification uses multiple types of data and data sources. There are three critical types of data needed:

1. **Historical forecasts**
2. **Historical observations (what actually happened)**
3. **Historical data on disaster impacts**

Often, the more data used during a forecast evaluation, the more confidence there is in a forecast's skill.

Often, the more data used during a forecast evaluation, the more confidence there is in a forecast's skill. However, disasters are rare events, by definition, so finding relevant datasets with several years or decades of information can be difficult. Step by step processes on forecast verification are detailed in the Climate Centre's Guidelines on Forecast Verification and the World Meteorological Organization's Forecast Verification Research.

Forecast verification is an essential step to determine which forecast tools should be used in an impact-based forecasting and warning service. Detailed information on forecast verification is provided in ***Chapter 7.***

Bringing the risk assessment together

The presentation and communication of risk forms the core of an impact-based forecast or warning. Risk matrixes and risk mapping are two tools frequently used to communicate risk.

A risk matrix approach is more subjective and qualitative than the risk mapping approach. Risk mapping provides detailed forecasts and warnings which satisfy context or sector specific challenges. For example, organisations with a remit to respond to weather and climate events favour risk mapping because it can be easily translated into intervention maps. Intervention maps highlight where anticipatory actions should take place, or where response actions are most likely to be needed. When there are limited resources, these intervention maps help to prioritise areas where the most severe impact is forecasted.

Risk matrixes and risk maps are used individually and in combination to present assessments of risk for impact-based forecasting. Individual national hydrological and meteorological service and partner organisations should identify the most appropriate approaches for their program development.

The responsibility for generating risk matrixes, risk maps, or any other tools which can be used to help present the level of risk, varies from country to country. In some, the national hydrological and meteorological service generates risk maps, in others the civil protection authority or the humanitarian sector generate maps. However, irrespective of where the risk assessment information is collated, risk assessments are co-produced with partners.

It is important that every organisation involved understand who is responsible for generating risk information, how risk information is used in impact-based forecasts and warnings, and how risk information is communicated to other organisations and members of the public.

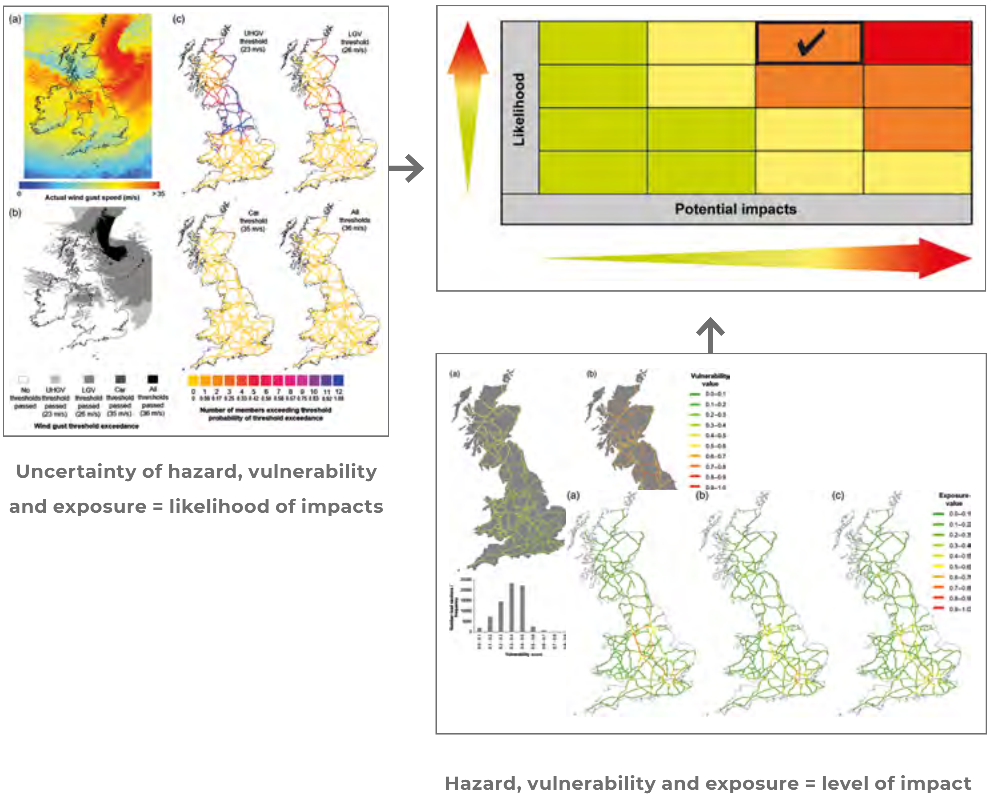
Risk Matrix

Risk maps are an effective way of combining forecast hazard, vulnerability and exposure data into an easy to interpret visual aid.

A risk matrix plots the level of impact against the likelihood of impacts occurring. 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*.

In the example of the UK Risk Matrix (see Figure 8), level of impact is plotted along the horizontal axis and the likelihood of impacts is plotted on the vertical axis. A checkmark identifies the current forecast, showing the level of risk for that impact-based warning.

Figure 8. UKMO Risk Matrix for Vehicle Overturning (*Hemmingway & Robbins, 2020*)



Before and during a climate or weather event, the hazard forecast certainty may change to be more or less certain. The assessment of the likelihood and level of impacts will also change. A matrix facilitates monitoring and communicating a forecast or warning as the event progresses. Users can follow the progression of the forecast and adjust decisions and actions required in response to the changing certainties and severity levels.

To build a risk matrix, national hydrological and meteorological services, along with partner organisations, need to identify:

- Hazards with impacts that affect organisations and/or members of the public
- Who and what is exposed (and vulnerable) to hazard impacts?
- Magnitude or level of impacts that affect at-risk population or assets (e.g. infrastructure)

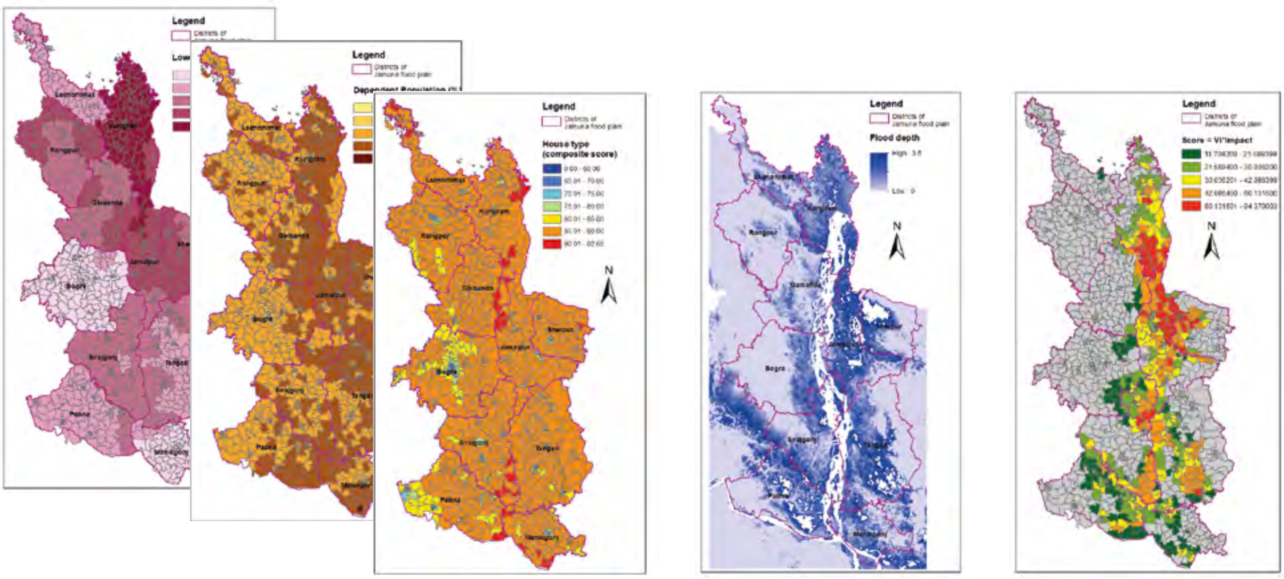
The details required to build a matrix depend on the programs being developed and are dictated by user requirements (for more information see *Chapter 2. Understanding Users*)

A risk matrix can be a useful communication tool for users who understand risk, such as national hydrological and meteorological services, disaster risk reduction and management agencies, civil protection, and humanitarian organisations. However, a risk matrix can be misleading to anyone who does not understand risk assessments. Recommendations on communicating risk are included in *Chapter 6. Communicating & Disseminating Impact-based Forecasts and Warnings*.

Understanding the potential impacts of a hazard is only the starting point for many organisations with a remit to mitigate the impacts of weather and climate events. The humanitarian sector is increasingly using impact-based forecasting, and is developing systematic approaches that use impact-based forecasting to trigger early actions aimed at minimising the impact of weather and climate events.

By working in partnership, the Red Cross Red Crescent has developed impact-based forecast intervention maps. These maps highlight and prioritise where early actions should take place.

Figure 9. Red Cross Red Crescent Forecast-based Financing: Impact-based Intervention Map for Jamuna River Basin, Bangladesh



Incorporating production time and updates

The lead time for a hydrometeorologist to produce a forecast or warning will vary depending on the type of product. Rapid onset hazards require rapid issuing of impact-based forecasts and warnings to maximise the time available to users to process and act.

Keeping impact-based forecast services simple reduces the time needed for production and increases the time available to users to interpret and act upon the information.

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

- 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 humanitarian actions influences the required lead time for forecasts and warnings (Coughlan de Perez et al. 2016). The following table highlights a Forecast-based Finance program for flooding in Uganda, where different actions require different lead times.

Figure 10. Actions Selected for a Forecast-based Financing System for Flooding in Uganda (*Coughlan de Perez et al., 2016, p.3553*)

Action	Time required to complete the action (implementation time)
Water storage and purification: distribute jerry cans, soap, and a 30-day supply of chlorine tablets to vulnerable households.	4 days to complete
Water drainage: dig trenches around homes to divert water.	4 days to complete
Food storage: bag vulnerable items and move to storage facilities on high ground.	7 days to complete

Hydrometeorology does not always provide a long enough lead time to allow for anticipatory. However, life-saving early actions can be possible at short lead times. In Bangladesh for example, the Bangladesh Red Crescent uses an impact-based forecast with a 30-hour lead time to start moving people and their livestock and belongings to safety. Even outside of the optimal lead time, when anticipatory actions would not be possible, forecast and warning information may still be useful to a range of users. Disaster managers may still be able to use the information to prepare to respond, and individuals may be able to make rapid, life-saving decisions.

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.

Changes in observed conditions may also warrant a forecast update. Real-time monitoring of conditions and impacts in the forecast area can help producers adjust impact-based forecasts and warnings in developing situations. Impact reports from sectors responding to weather and climate events, as well as impact information from monitoring media outlets and d social media can all be used to adjust impact-based forecasts and warnings.

Impact-based forecast and warning production software

Where possible, the time needed to generate a forecast or warning can be reduced by automation. Some national hydrological and meteorological services have built their own production software or tools. For example, the South African Weather Service (SAWS) has built a warning generation tool for disaster mangers in Microsoft Excel. Their matrix approach uses a number system for each box in the matrix (Poolman et al., 2018). Actions are assigned to each of the numbers in the matrix. These actions range from making sure disaster management officials are simply aware of the warning issued (a #1 warning) to alerting the Mayor and instructing disaster managers prepare to dispatch resources and possibly relocate communities (a #10 warning). During an event, SAWS quickly assesses the impacts, draws a warning area, and allocates the relevant warning number. This is communicated to disaster managers via SMS and they then translate the number into the appropriate action. This system enables efficient, rapid generation and communication of warnings in changing severe weather situations. The strategy also reduces the quantity of textual information forecasters provide to disaster managers. As many disaster managers do not have access to their laptops when in the 'field', supplying warning numbers as an indication of severity and possible actions via SMS to their portable phones saves time and keeps disaster managers up to date. More detailed information is sent to the disaster manager via email.

In the UK, the Met Office has built its own 'Warnings Manager' software. Partners, stakeholders, and members of the public were consulted to identify what types of information are required in a warning. The 'Warnings Manager' software allows meteorologists to select pre-populated hazard and impact information, which reduced warning production time from 30 minutes to 5 minutes, on average.

In Indonesia, real-time forecasts of extreme events are incorporated into the InaSAFE software to identify which people and assets are likely to be impacted by an upcoming event. InaSAFE generates prototype impact-based forecasts and warnings which will be used by the Indonesia Red Cross to activate its Forecast-based Financing system and implement anticipatory actions.

Content of impact-based forecasts and warnings

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 hazard beginning 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)

Designing impact-based forecast and warning content is covered in ***Chapter 4. Partnerships and collaboration***)

Pilot projects

Pilot projects are not a required step for producing impact-based forecasts and warnings, but a pilot project creates a safe environment in which to develop and test a service that is fit for purpose and is therefore recommended.

A pilot project group is made up of the organisations producing forecasts and warnings and the organisations or individuals who will be using the impact-based forecast service (this often includes organisations with access to risk data). By including users in every stage of the development of impact-based forecasts and warnings, the final forecast or warning is more likely to meet user requirements.

Pilot project groups can:

- Ensure the impact-based forecasts and warnings remain relevant to the users by seeking regular feedback and iteratively improving designs to overcome barriers to successful forecasts and warnings and sharing of information.
- Build relationships between the producers of the forecasts, risk data holders and the users. These relationships are enablers, encouraging organisations and individuals to use the impact-based forecasts and warnings being produced.
- Test the impact-based forecast and warning production chain, ensuring technical resilience before production is fully launched.
- Test and iterate the design of impact-based forecasts and warnings for clarity, ease of use and accessibility.
- Quality control designs and production methods against the needs of users.
- Raise awareness and promote impact-based forecasts and warnings.

As described in the following table, a range of barriers and enablers can affect the success of forecasts and warnings (Soares & Dessai, 2016). Pilot project groups should ensure barriers are avoided and enablers are activated in the production of impact-based forecasts and warnings.

Table 6. **Barriers and Enablers to Forecasts and Warnings**

Barriers	Enablers
▸ Timing of the forecasts and warnings ▸ Perceived lack of reliability of forecasts and warnings ▸ Lack of interaction between producers of forecasts and warnings and the users ▸ Lack of relevance of forecasts and warnings for the organisation's activities ▸ Lack of awareness of forecasts and warnings ▸ Level of financial investment and resources required to use forecasts and warnings in the organisation ▸ Tradition of performing historical variability analysis (due to preference to maintain existing practise or perception of reliability of this type of analysis) ▸ Lack of understanding regarding the added value of forecasts and warnings ▸ Lack of institutional arrangements for sharing data (forecast and risk data) ▸ Risk data quality and scale	▸ Timely delivery of forecasts and warnings ▸ Actionable and more reliable forecasts and warnings ▸ Ongoing relationships with the producers/ providers of forecasts and warnings and accessibility to these forecasts (e.g. via protocols between governmental organisations) ▸ Level of resources and expertise in the organisation(s) ▸ Perceived advantage of using forecasts and warnings particularly in the private sector ▸ Ability to develop specific products in regions where forecasts and warnings reliability is higher (e.g. tropics) ▸ Knowledge-seeking behaviour ▸ Clear understanding of risks among all the key actors, to determine what exactly can be done to reduce risk in the window of time between a forecast being issued and impacts occurring ▸ Innovative use of resources, tools, systems, approaches to overcome the information challenges in forecast and risk data.

Examples of visualisation of impact-based forecasts and warnings intervention maps

Africa –Malaria Early Warning System

The International Research Institute for Climate and Society developed the map below which shows malaria transmission risk over Africa, using a Vectorial Capacity (VCAP) model that defines precipitation and temperature as the limiting factors of malaria incidence. VCAP shows the daily rate at which future malaria inoculations could arise from a currently infected case. Here, VCAP is used as a convenient way to express transmission risk or receptivity of an area to malaria.

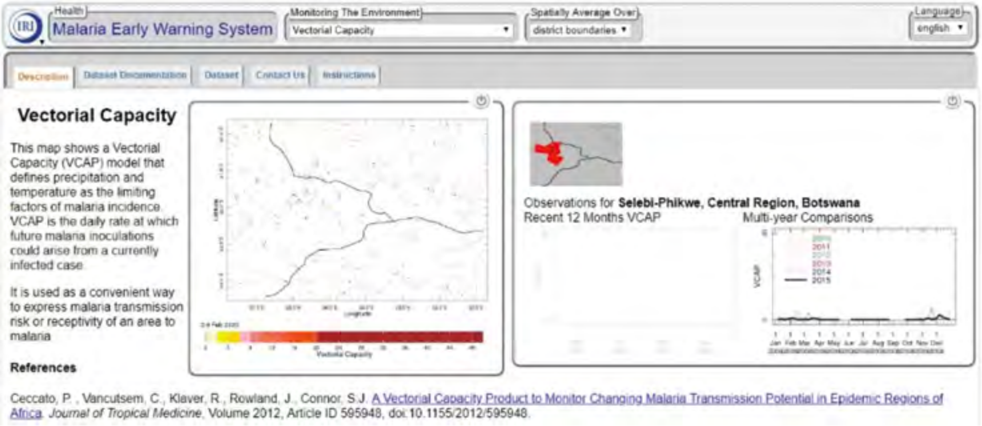


Figure 11. IRI VCAP Model - Malaria

Canada – producing risk maps with the aid of machine learning and artificial intelligence

The IBM Weather Company has developed an impact-based power outages tool for the utilities sector. The tool uses past weather event data and applies machine learning and artificial intelligence to improve the tool as successive storms occur. NB Power in Canada has been using the Outage Prediction tool to reduce power outages and financial costs resulting from the damage caused to the power network in a winter storm.

Peru – Disaster Management Office Risk Scenarios

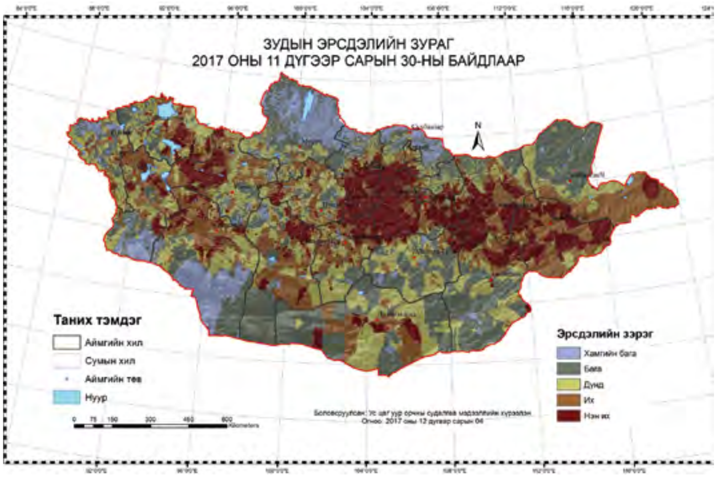
Figure 12. Meteorological Notice - Risk Scenario according to Rainfall Forecast

In Peru, risk scenarios are produced to highlight areas where impacts are possible, based on forecasts for heavy rain and frost and cold. The risk maps are displayed online and an accompanying technical forecast document is also available.

Mongolia – *Dzud* Forecast-based Financing and Risk Maps

In Mongolia, the Red Cross uses impact-based forecasting to anticipate extreme winter conditions, locally known as *Dzud*. Working in collaboration with Japan's Nagoya University, Mongolia's Information and Research Institute of Meteorology, Hydrology and Environment investigated major *Dzud*-producing factors during the period 1999-2014 (Nandintsetseg et al., 2018). This included natural (pasture/climate anomalies) and socio-economic (human/livestock) vulnerability variables. *Dzud* risk maps were developed using multi-criterion analyses, based on data including pasture carrying capacity, forecast temperature, snow and drought. The risk maps, based on historical analysis and risk assessment, are incorporated into the [forecast-based financing] approach of Mongolian Red Cross and form the basis for the development of the *Dzud* Early Action Protocols, which trigger the automatic release of funds, before the impacts of Dzud are felt. The funds are used to support vulnerable individuals and communities with the supply of animal feed and care supplies.

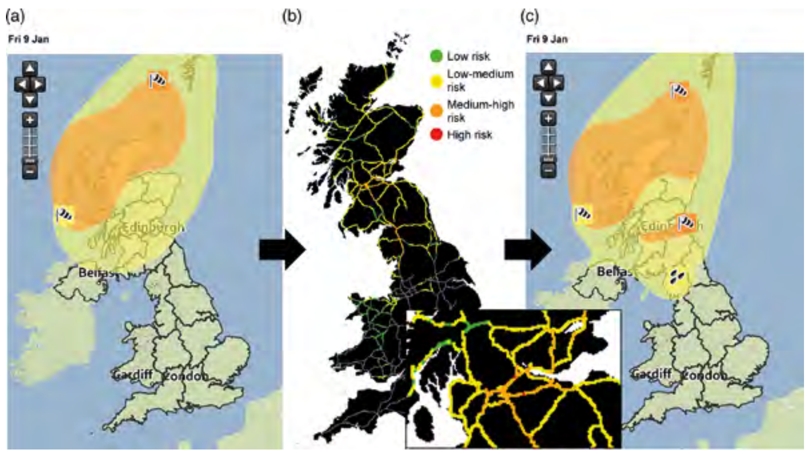
Figure 13. *Dzud* Risk Map, Mongolia



When hot and dry summers reduce pasture availability, weakened livestock may not survive a subsequent *Dzud* because of the harsh cold or lack of fodder. In the winter of 2017/18, an impact-based forecast signalled a high risk of *Dzud* in multiple areas of Mongolia. Using forecast-based financing, the Red Cross provided targeted cash transfers and animal care kits to vulnerable herder households across the entire country, in areas that would be most affected by *Dzud*.

A robust, quasi-experimental study showed that by providing early assistance in December and January, *before* winter conditions reached their most extreme, the Red Cross intervention effectively reduced livestock mortality by up to 50% and increased offspring survival for some species, thereby helping to secure future livelihoods.

UK - Natural Hazards Partnership [Vehicle Over Turning Model]



Strong winds in the UK cause vehicles to overturn and block major transport routes, resulting in significant disruption to the road network. The UK Met Office worked with members of the [Natural Hazards Partnership] to develop a tool which highlights road routes with a higher risk of vehicle overturning during strong wind events (see case study above).

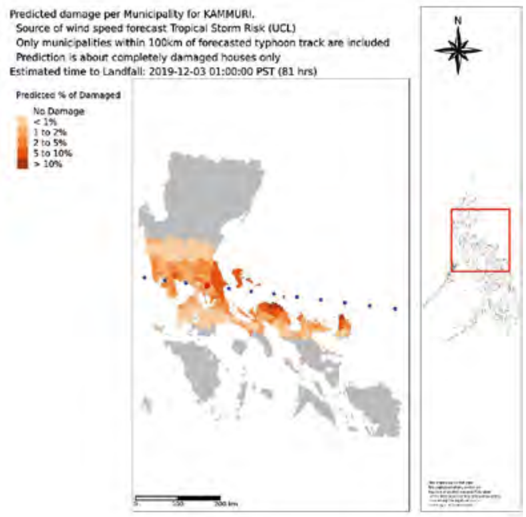
Figure 14. Evolution of the UK Met Office Amber Weather Warnings for Wind Showing (a) The Amber Wind Warning valid on Friday, January 9, 2015, Issued on Wednesday, January 7; (b) The Vehicle Over Turning (VOT) Model Output from January 8, 2015, 21:00 U

The Vehicle Overturning Model uses probabilistic MOGREPS-UK (UK Met Office Ensemble Forecast Model) wind speed and direction data with a lead time of 1.5 days. An estimate of the probability that a strong wind event will occur is integrated with road network vulnerability and exposure data. The output from the Vehicle Overturning Model is used by meteorologists to inform the level of impact used in warnings.

Case Study Forecast-based Financing in the Philippines

Philippines Red Cross and German Red Cross Forecast-based Financing system

In December 2019, the Philippines Red Cross, supported by the German Red Cross, used Forecast-based Financing to support the population of the Bicol region, ahead of Typhoon Kammuri (Tisoy), as a part of small test activation of their anticipatory actions. Using weather forecasts and warnings, the Philippines Red Cross monitored the development and progress of the typhoon over the preceding week, deploying staff and volunteers to the communities at risk to assist the population in protecting themselves and their livelihoods from impacts.



The Forecast-based Financing project in the Philippines used an impact-based forecasting model developed with support from the Netherlands Red Cross 510 data initiative, to identify municipalities with expected severe impacts. Trained on 27 historical typhoon events, the model uses typhoon predictors (such as windspeed and track), geographical information (such as ruggedness, landslide risk), and housing vulnerability (such as housing roof and wall material).

The Philippines Red Cross volunteers and staff, supported by the German Red Cross, carried out the following early actions:

Figure 15. Predicted Percentage of Fully Damaged Houses for Typhoon Kammuri in the Philippines, Impact-based Forecasting Machine Learning Model

- Strengthened the housing in two communities (e.g. by tying down roofs) in Camarines Norte. Shelter strengthening kits and instruction materials specifically for this purpose had been developed earlier in 2019 in collaboration with construction experts.
- Supported early harvesting of Abaca trees in five communities on Catanduanes island, employing more than 100 community members. This ensured vulnerable farm workers could still process the fibres and generate income after the storm. In past storms, when Abaca trees were destroyed, farmers incurred significant losses and workers who processed the fibres could not earn an income.
- Evacuated the livestock of two communities in Camarines Norte. Communities were chosen that had already lost large parts of their livestock during tropical depression Usman in 2018. The Red Cross Forecast-based Financing team identified a central elevated site (200m from the shelter for the population) and employed 17 community members to fence off the area. The livestock evacuation was carried out in close collaboration with the provincial authorities who provided trucks.

Case Study Developing impact-based forecasting in data sparse areas in Uganda

Uganda Red Cross Society Forecast-based Financing pilot (Coughlan de Perez et al., 2016)

The Teso region of north-eastern Uganda is a swampy region, prone to river flooding and waterlogging during the two rainy seasons centred in May and October. Many of the area's residents farm and raise livestock. Flooding typically causes impassable roads, loss of crops, outbreaks of waterborne diseases, and the collapse of houses and latrines. The Uganda Red Cross Society needed a system to release funds and enable predefined anticipatory actions. Triggering the release of funds and actions required impact-based forecasts. Rivers in this region had no calibrated hydrological models available. An alternative methodology for calculating flood risk was therefore developed and piloted in the Teso region.

Historical observation data was taken from the only local Akokoro river gauge (2009-2013) and from historical daily forecasts from the Global Flood Awareness System (GloFAS) (2009-2014). GloFAS uses model climatology to forecast extremes or anomalies in river flow relative to historical climatology runs of the model. This approach addresses the lack of representation of local-scale channel geometry and bias in the precipitation forcing. In order to link the model climatology to the real world, percentiles, rather than absolute values of the forecast, were used.

The percentile of discharge that is qualitatively associated with reported flood events of the past few years, when avoidable losses were observed, was calculated, recognising that the relationship between water levels and flood risk will vary overtime due to changing vulnerability and exposure. Reports of flooding and impacts came from the humanitarian records in the Desinventar database (UNISDR, 2011), the Uganda Red Cross Society internal disaster records, and the newspaper repositories of the Daily Monitor and New Vision, two national Ugandan newspapers.

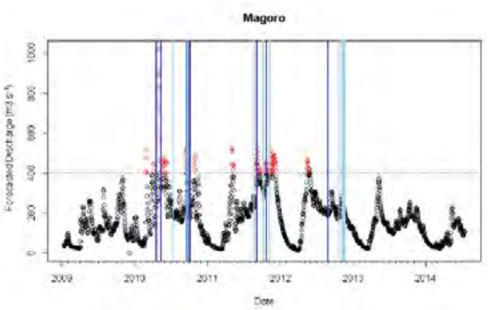


Figure 16. Historical Discharge Magoro

Figure 16. estimates the percentile of discharge that is associated with flooding in the project region, by plotting the historical median water levels forecasted at a lead time of 0 from the GloFAS model. Comparing this with historical floods (dark blue lines), and media reports from the district (light blue lines), the 95th percentile (horizontal red line) was qualitatively selected as a proxy for disaster.

In the 6 years between 2009 and 2014, this percentile, or danger level, would have been exceeded in 2010, 2011, and 2012. In April 2010, reports indicate that 12 secondary schools and 7000 people were affected by flooding in the area, followed by crop losses due to waterlogging in May 2010. Flooding continued to be reported through September and October of that year, affecting several regional roads. This corresponds well to the simulated discharge for those years. Forecasted discharge (circles) in Magoro sub-county represented by a GloFAS forecasts ensemble median at lead time 0. Dates of disasters in the regions along the Apapai River are indicated by dark blue vertical lines, as per the databases of the Uganda Red Cross Society and Desinventar. Newspaper reports of flooding in the district of Katakwi are indicated by light blue vertical lines. Small tick marks on the x axis correspond to months within a year. The horizontal dashed red line indicates the 95th percentile of estimated discharge; dates with discharge above this threshold are coloured in red.

In 2015, the forecast-based financing system based on this method of analysis triggered action for the first time in Uganda. Water purification tablets, soap, shovels, and storage bags were distributed to the at-risk population. This example was the beginning of the Red Cross Red Crescent integration of impact-based forecasting in its decision-making process for early action, further development has been made in the last 5 years to integrate vulnerability and exposure in the impact-based forecast process.

Chapter 6. Communicating & Disseminating Impact-based Forecasts and Warnings

Netherlands Red Cross (NLRC) Caribbean Branches helping to disseminate warnings of the approach of Hurricane Maria in St Maarten, Saba and St Eustatius. Photos: NLRC via IFRC

An accurate forecast is worthless if it is not communicated effectively and it is not received with time to mitigate impacts.

An actionable impact-based forecast and warning needs:

- Development: creating data-based hazard and impact risk assessments as discussed in ***Chapter 3. Understanding Risk and Impact*** and ***Chapter 5. Producing Impact-based Forecasts and Warnings***
- Communication and Dissemination: selecting which information to communicate and choosing appropriate methods and technologies to disseminate messages to users.

These roughly align with the World Meteorological Organization guidance delineating the difference between traditional forecast development and impact-based forecast and warning development, dissemination, and response.

A 'well communicated' forecast or warning is defined as one that is disseminated in a timely manner, is clear and free of jargon, easy to use, easy to understand, consistent, credible, relevant, and enables users to make decisions and take actions that result in the reduction of impacts. If the design, communication, and delivery of forecasts and warnings are focussed on, and informed by, the needs of the target audience, communication is more likely to be successful.

The amount of literature on how to communicate risk and impact-based forecasts is increasing rapidly. Therefore, the advice given in this section is based on latest thinking in communicating risk and the experiences of national hydrological and meteorological services that have developed or are developing impact-based forecasting.

Communicating impact-based forecasts and warnings

As with all communication, communicating impact-based forecasting requires a detailed understanding of the target audience. The following questions will help identify audience characteristics and the best communication tools to use:

- Is the forecast or warning aimed at the public or expert users? Consider the differing needs of humanitarian sector (Red Cross Red Crescent National Societies, NGOs, UN agencies; individuals or business; local disaster managers and/or government ministries/agencies).
- What language(s) is the audience familiar with? What language(s) is the audience most comfortable with?
- How do users access forecasts and warnings?
- What business continuity measures need to be considered for failures of normal dissemination routes?
- How should the information be presented? What visuals, word choices, and colour schemes are culturally relevant, understandable, and practical?
- How can levels of risk be communicated to promote decision-making and action?
- 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?)
- What do users not need to know? Are details of the hazard forecast essential in understanding the impact, or would presenting the expected impact without meteorological information be sufficient?

Past disasters, such as Hurricane Katrina in 2005 or the Pakistan floods in 2010 reveal risk communication failures (DKKV, 2011). Inconsistent messaging, unclear information about response actions, loss of trust and credibility in official institutions responsible for early warning, and uncoordinated disaster management contributed to the increasing disaster risk.

People-centered and culturally relevant risk communication is a key to improve vulnerability and risk reduction in the context of extreme events, particularly in the context of people-centered early warning (DKKV, 2011).

Weak and insufficient risk communication as well as the loss of trust in government institutions in the context of early warning or climate change adaptation can be seen as a core component of institutional vulnerability (Cardona et al.,2012).

What to communicate

Users of impact-based forecasts and warnings need to know the answer to four questions:

Table 7. User Related Questions for Impact-based Forecasting and Warning

Key questions	Information users require	
	Sector specific users	Individuals/members of public
What is going to happen?	▸ 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	Summary of the hazard *impacts*, avoiding technical terms
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?	▸ Assessment of the risk ▸ May include risk matrices, risk maps/ intervention maps ▸ Where will impacts take place ▸ How severe will the impacts be?	Clear, jargon-free explanation of risk, focussed on impacts
What can I do to reduce impacts?	Organisations will have actions and/or response plans to implement on issuance of the impact-based warning	Advice and guidance on what actions can be taken to prepare

In practice, the level of information to answer these four questions will vary. Tailoring impact-based forecasting communication to different audiences makes a marked difference in how effectively the recipient can act on the communicated warning. Partnerships are often needed to provide all of the information users require. For example, advice to individuals on what to do to reduce impacts will often be provided by disaster managers or governments. Advice on how to reduce impacts for sector specific users will come from within the authorities or organisations involved, such as in the form of the Early Action Protocols used by the Red Cross Red Crescent National Societies and Common Alert Protocols advocated by World Meteorological Organization.

Impact-based forecast and warning design

Well-designed impact-based forecasts and warnings will be clear, easy to use, and relevant.

Consideration should be given to a number of design factors, including:

- *Communication channel:* the channel through which users access warnings affects the design of impact-based forecasts and warnings. For example, forecasts and warnings designed to be viewed as a paper document will be presented differently to a forecast or warning designed to be used on a mobile weather app, in a text message, or on a website.

- *Accessibility:* the design of the impact-based forecast or warning should ensure accessibility for the user. For digital channels, such as websites and apps, the Web Content Accessibility Guidelines outline design recommendations for providing optimum accessibility.

- *Use of colour:* Colour can be used very successfully to help highlight or compliment information within an impact-based forecast or warning. However, different colours can be interpreted differently by users, which might affect how the forecast or warning is understood. Colour vision deficiencies can affect how users interpret forecast and warnings which use colour to indicate severity. Coloured text over a coloured background can be difficult to read. Colorable and Colorsafe provide tools to test accessibility of colour combinations.

- Text size and font: larger text sizes may be needed for different communication channels than others. Fonts can also affect how easily something can be read and understood.

White, bold text over a red background is easier to see than black text on a red background	**White, bold text over a red background is easier to see than black text on a red background**
Font and text size make a difference	Font and text size make a difference

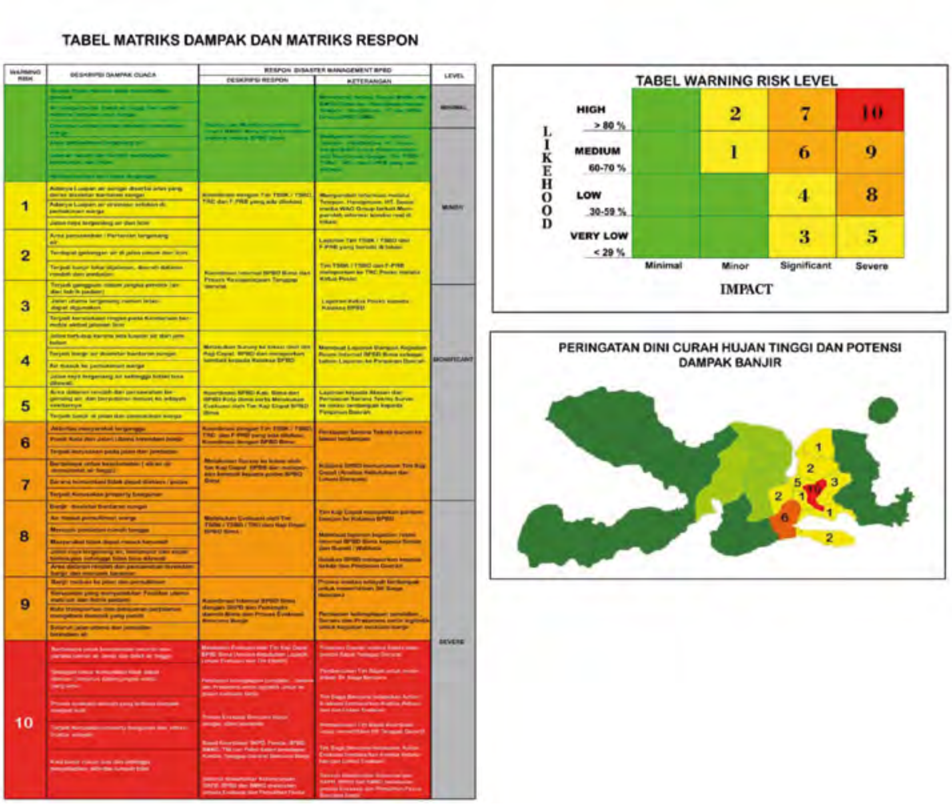
Figure 17. Font and Size for Effective Communication

- Terminology: it is important to use terminology and language that is appropriate for the audience.

- Flexible design: the information required in an impact-based forecast and warning may be the same for a range of users, but the way users access the information may vary. The same information may need to be presented in a number of different ways across a number of communication channels to maximise access for users. For example, if a forecast is going to be issued as a PDF attachment to some users and via the radio to other users, there will be aspects of the forecast which may not be easily communicated across both channels. Risk maps are great visual tools for communicating risk in a PDF. However, forecasts for radio broadcasts may need to include written statements to describe the information in the risk map, while the risk map can be included within a PDF.

- Design of a risk matrix: national hydrological and meteorological services that use risk matrices in impact-based forecasting have followed a consistent approach. Many national hydrological and meteorological services use a system of colours in the matrix, from green to red, to help communicate the level of risk. The colours can be tested with users to ensure that each colour is being interpreted as intended. The Indonesia Agency for Meteorology, Climatology, and Geophysics has developed a matrix which uses colour and numbers to communicate risk. The numbers correspond to specific response actions. The Indonesia Agency for Meteorology, Climatology, and Geophysics worked in partnership with the Indonesian National Board for Disaster Management to develop the response actions. Their impact-based warnings to the Indonesian Board for Disaster Management include the number, colour, and area affected.

Figure 18. Indonesia Warning Risk Matrix, Table of Response Actions and Warning Map for Indonesian Board of Disaster Management



- Designs of risk maps: The same considerations outlined above are applicable to the design of risk maps. The Understanding Risk Community, an initiative of the Global Facility for Disaster Reduction and Recovery, has developed a number of well-designed risk maps. Examples can be found here.

Consistency

When national hydrological and meteorological services and partners issue forecasts and warnings with different designs for the same weather or climate event, it is important that the information in each product does not contradict the information in another product.

Inconsistent textual and visual information across forecasts and warnings detrimentally affects decision-making behaviour. The information provided in impact-based forecasts and warnings must be consistent, both textually and visually, across all communication channels, in order to lead to effective decision-making.

Inconsistencies may arise when more than one organisation issues or communicates forecasts and warnings for the same area. When forecasts and warnings are issued for border regions, it may be helpful to develop forecasts and warnings which share a consistent approach and terminology (e.g. HIGHWAY project).

Partnerships and engagement with private weather services and media broadcasters can help improve consistency in how impact-based forecasts and warnings are communicated and ensure the authoritative voice for impact-based forecasts and warnings is maintained.

Case Study Inconsistent Forecasts and Warnings Switzerland

'In Europe, all national hydrological and meteorological services are obliged to issue official and authoritative weather warnings on behalf of their governments to warn authorities and the public at large of hazardous weather. In addition to these official warnings from the national hydrological and meteorological services, private weather companies can also publish and disseminate their own weather warnings. Differences between map colour-coding, warning thresholds, and weather models increase the risk of apparent (or actual) inconsistencies in the warning information disseminated by different weather providers for a specific point in time' (Weyrich et al, 2019).

For instance, four weather warnings were issued for the same, rainy day in November 2017, covering an area near Lake Lugano in Switzerland. Meteorologically, the forecast rainfall amounts could all be verified as accurate. However, the differences in visualisation colour, rainfall amounts, and time periods, all make the warnings seem inconsistent and could lead to users to make different decisions based on seemingly different information, or worse lead to a distrust in all forecasts in general.

Provider	Visualization color	Interpretation (mm)	Time period (hr)
MeteoSuisse (MCH)	Yellow	>70	24
MeteoNews	Oragne	60-90	48
Meteocentrale	Purple	<100	24
SRG SSR (SRF Meteo)	Yellow	60-100	24

Figure 19. Different Services, Different Warning Information

Communicating risk

The risk information within impact-based forecasts and warnings is critical for users and it is important to communicate the level of risk in an understandable and accessible way. Many users need clear descriptions. A clear description details the impacts forecast to occur, the severity of the impacts, and how likely the impacts are. Popular tools for communicating risk are risk matrixes and risk maps (see ***Chapter 2. Understanding Users*** and ***Chapter 5. Producing Impact-based Forecasts and Warnings***). For sector specific or expert users, matrixes and maps can communicate risk effectively. However, developing tools that are culturally relevant and easily understood by the target audience should be the primary goal.

The UK Met Office and the Barbados Meteorological Service, for example, have found that a matrix can be a useful tool for civil protection and disaster response organisations, but it is not understood by all sector users. To help civil protection and disaster response workers understand the matrix, the UK and Barbados developed videos to explain how the matrix works in weather warnings.

Communicating forecast and warning scenarios – what is the 'best message'?

For any given forecast climate or weather event, there are usually a range of possible forecast outcomes. This range will vary based on the potential magnitude of the hazard, the severity of the associated impacts and the likelihood of the impacts occurring. Sharing information with users about the uncertainties in the forecast and risk assessment can be helpful.

Figure 20. UK Met Office Storm Map

For example, as a cyclone develops and begins to track towards a coastal city, a number of forecast outcomes will be possible for that city. The initial forecast suggests that the track of the cyclone is most likely to veer away from the city and there is a high likelihood of no impacts in the city. However, a few models bring the cyclone much closer to the city, with one model suggesting the forecast track will bring the cyclone straight through the centre of the city. In this scenario, there is a low likelihood of devastating impacts. The hydrometeorologists and partners must decide what the best message is to communicate to users: the most likely forecast scenario, with no impacts, or the much less likely but far more impactful scenario. A typical decision might be to issue an impact-based warning for the less likely but more impactful scenario. In this scenario, different users might also require information with different degrees of detail: the public in the city at risk will probably need to know that very severe impacts may occur in their area, so they can evacuate; while organisations that carry out early actions might be interested in the different likelihoods of impacts per region, so they can prioritise their support in areas most likely to be severely impacted. With early actions and decisions critical to minimising the impacts of a cyclone, users need information early, however low the likelihood, to ensure they have time to prepare and act.

Communicating uncertainty

All impact-based forecasts and warnings contain uncertainties; the method of communicating those uncertainties will vary depending on the target audience.

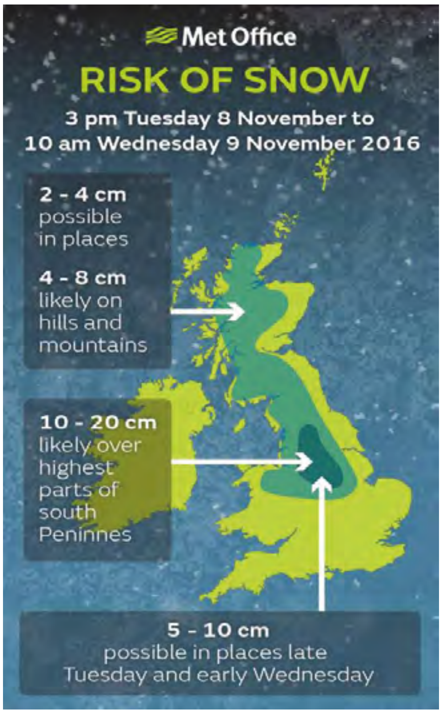
Uncertainty is already part of the risk assessment within impact-based forecasts and warnings, but any design decisions in the forecast and warning will affect how uncertainty is implicitly or explicitly communicated.

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.

The UK Met Office has compiled a short lexicon of specific words to use to replace the use of 'very low' to 'high' likelihood descriptors.

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.

Figure 21. UK Met Office Snow Risk Warning



Advice and guidance for users: 'what can I do to reduce impacts?'

Sector specific users

Disaster risk management agencies, government departments, humanitarian agencies and other sector specific users, likely have contingency plans and early action plans that describe clearly what type of actions the institution needs to take based on an impact-based forecast service. Such plans are developed months, ideally even years, in advance of severe extreme weather events. This ensures early actions and the necessary structures and procedures are ready when an impact-based forecast or warning is issued.

For example, the National Weather Service and Hydrology of Peru (SENAMHI) produces forecasts for heavy rain, frost, and cold. Based on these forecasts the National Centre for Disaster Risk Estimation, Prevention and Reduction (CENEPRED) produces risk scenarios to highlight areas where impacts are possible. These climatological forecast warnings and risk scenarios form the Peruvian Red Cross Early Action Protocols (EAPs) for floods and cold waves. The EAPs activate when the forecast warnings indicate a certain level of impact will be exceeded. The Red Cross, together with civil protection agencies and municipal authorities, prioritise high-risk areas and implement early actions to reduce the hazard impacts on vulnerable population in advance.

For individuals/members of public

The general public understands hydrometeorological warnings and perceives risk better if the warning describes the expected impact (Potter et al. 2018) Adding behavioural recommendations, alongside the expected impact further improves the effectiveness of impact-based forecasts and warning. Perhaps obviously, people are more likely to engage in actions which will reduce impact when given additional advice and guidance on mitigative actions.

Figure 22. Perception of Information for Four Types of warnings (standard or impact-based, with or without behavioural recommendations) (*Golding et al 2019*).

Bars indicate how much participants agreed or disagreed on a five-point Likert scale from 'totally disagree' to 'totally agree' with each of the five perception attributes. Error bars indicate the 95% confidence interval.

In impact-based forecasting, advice and guidance on what to do likely come from institutions or organisations with a mandate for providing advice in crises. Advice and guidance may be event-specific or more general. For example, the World Health Organization has developed infographics providing generic advice which can be used before and after any typhoon.

Figure 23. WHO typhoon advice

Hydrometeorological jargon

A lot of the terminology taken for granted within national hydrological and meteorological services is often not understood by outside audiences. When composing forecasts and warnings, great care should be taken to use language appropriate for the audience. Partners, stakeholders, and potential users (including member of the general public if they are a target audience) should provide feedback on any proposed language and designs.

Technical terms should be avoided. Which terms to avoid will vary, depending on the audience, but may include terms that describe weather parameters, areal extent, intensity of precipitation, and wind direction. Where terminology may cause confusion or be open to misinterpretation, alternatives should be sought, such as symbols or images, to communicate the forecast or warning.

> *We found that compass points were not understood. In fact, many people didn't know which way was north, so it was clear that using compass points to describe what direction the wind was coming from wasn't going to work.*
>
> *We worked with the local communities and agreed that we could use geographic reference points to describe direction, such as the local towns.*
>
> *Lake Victoria HIGHWAY Project*

When we investigated how weather warnings were interpreted by members of the public, we found a number of terms and descriptions were causing confusion.

As meteorologists, we are really comfortable with terms we use to describe geographical extent, such as localised and occasional, but users didn't know what these mean. So we have started using phrases which are more meaningful to members of the public, such as 'in a few places'. When thunderstorms are forecast, we might say 'many places will stay dry but a few places will experience torrential rain' instead of 'localised thunderstorms are expected'.

We also found that the phrases we had been using to trigger action, Be Aware, Be Prepared and Take Action, were not driving the actions we had hoped. We used Take Action exclusively for high impact warnings, but we need people to be taking action for low and medium impact warnings too, if the impacts are to be mitigated. We have replaced these phrases with detailed impact information and linked our warnings to advice and guidance from our partner organisations.

Met Office used to issue Alerts and Warnings, but when we carried out research with members of the public, we found that they did not understand the difference between the two. We originally used the two terms to indicate differences in lead time, but as the forecast start times are in all of the warnings and the different terms were not adding any additional information, but were adding confusion, we removed alerts and now we just issue warnings: irrespective of the lead time.

Next Generation Warnings Project, UK Met Office

Language

Many countries have more than one official language, and communities often speak local languages which differ from the official language. Impact-based forecasts and warnings may need to be issued in more than one language. Alternatively, agreements can be put in place with partners or users to complete some of the forecast and warning translation work.

Around Lake Victoria, over forty languages are spoken. To get impact-based warnings to the local communities, the national hydrological and meteorological services and partners have developed a dissemination method which ensures local populations receive forecasts in a language they understand. Most communities living and working around the lake receive weather information via local radio. National hydrological and meteorological services developed translation guides, using input from local Beach Management Units. Local radio broadcasters use these guides to translate forecasts and warnings into the local language.

Channels and Technologies for Dissemination

The intended audience should determine the technology and channels used in disseminating an impact-based forecast or warning. The American Meteorological Society provides good practices for disseminating warnings.

Within an area, a range of organisations will likely disseminate impact-based forecasts and warnings. The national hydrological and meteorological service, or the civil protection agency, may be the lead organisation for disseminating forecasts and warnings, but other organisations may officially, or unofficially, disseminate forecast and warnings to a wider audience. For example, TV and radio broadcasters, humanitarian organisations, disaster managers, and civil protection agencies, can all help distribute impact-based forecasts and warnings. Establishing standard operating procedures between dissemination and communication partners will help to promote efficient and consistent impact-based forecast and warning services.

Some organisations and individuals that disseminate forecasts and warnings may also be strong local communicators, like TV weather presenters, news readers, radio hosts, community leaders, and local disaster managers. Such organisations and individuals must also understand the impact-based forecast information. Partnerships with these organisations build knowledge: resulting in all parties communicating a consistent message.

USA - Wireless Emergency Alerts (WEA)

'Once one of the 122 local National Weather Service offices hits "Send" on a warning they've created, that warning is sent, via a complex network to the National Weather Service Telecommunication Gateway (NWSTG). These important messages are then sent to the Integrated Public Alert & Warning System (IPAWS), a modernisation and integration of the nation's alert and warning infrastructure. When National Weather Service warnings reach IPAWS, they are pushed to commercial wireless carriers who broadcast the alert from cell towers in the threat area, straight to your cell phone.' NOAA

Bangladesh Met Department (BMD) in the lead upto Cyclone Fani
Photo: BMD/UK Met Office

> *Getting impact-based forecast and warning information to the informal communities of South Africa has been a challenge in the past. The South Africa Weather Service and partner organisations have worked with informal communities to find a solution.*
>
> *The community leader usually has a smartphone, or has access to one, and has contact with the local disaster managers. The community leaders agreed that when an impact-based forecast or warning is received that needs to be shared with the rest of the community, a flag will be raised. If it is a red flag, the community members will come for a meeting, and loud hailers will be used to get the message to community members.*
>
> *The Weather and Climate Science to Services Partnership project*

Case Study Evolution in risk communication in the UK Met Office impact-based weather warnings

Research into the performance of UK Met Office impact-based warnings found that members of the public, and a significant proportion of individuals working in civil protection and disaster response, did not understand the risk matrix used in warnings. As a result, the Met Office considered the needs of these two groups of users and revised the way risk is communicated within warnings. For individuals working in civil protection and disaster response, it was necessary that they understood the matrix as they were using the levels of risk within it to determine what actions they might need to take in the event of severe weather.

The Met Office devised two solutions for this issue:

1. A video which explains how the matrix works and the implications to emergency response if the matrix is not understood. The video is available to all civil protection and disaster response organisations.
2. A standardised training package delivered to groups of civil protection and disaster response practitioners, which includes understanding weather, the impacts it can cause and how to use weather warnings.

For members of the public, the Met Office also looked at alternative ways to communicate levels of risk so that the warnings did not have to rely on the matrix as the only solution to convey risk level. A study surveyed how the general public understood a collection of descriptive words for impact probability.

Participants were asked to complete three exercises, based on simple word sorting. The results of the exercises produced a list of words which have been incorporated into Met Office warnings and are used as a proxy for probability.

Identifying language to describe level of impact proved more difficult. Initially, impact levels were described as very low, low, medium, or high. Although 'very low' and 'high' could be readily translated into an understanding of impact level by some users, 'medium' was confusing. Alternative words were investigated, such as minor, significant, severe and extreme. The results showed that some of these descriptions were interpreted differently and inconsistently.

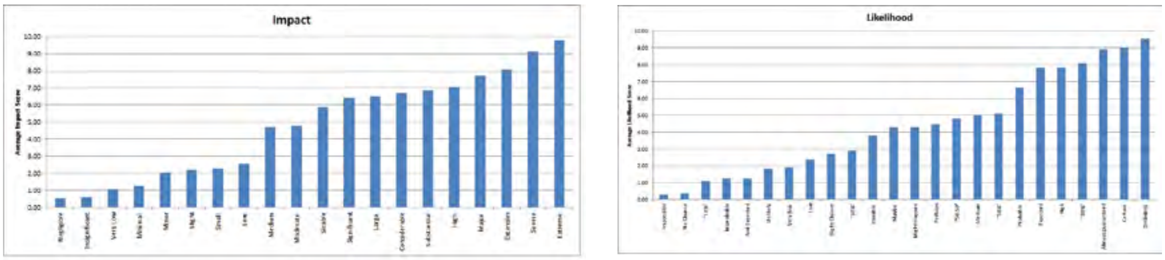


Figure 24. Initial Results from the UK Met Office Language Exercises for Descriptions of Probability

To solve this issue, the Met Office chose to abandon using single word descriptions of impact levels in public weather warnings. Instead, specific impacts are listed in each weather warnings clearly indicating what kind of sectoral impact to expect for the issued warning level.

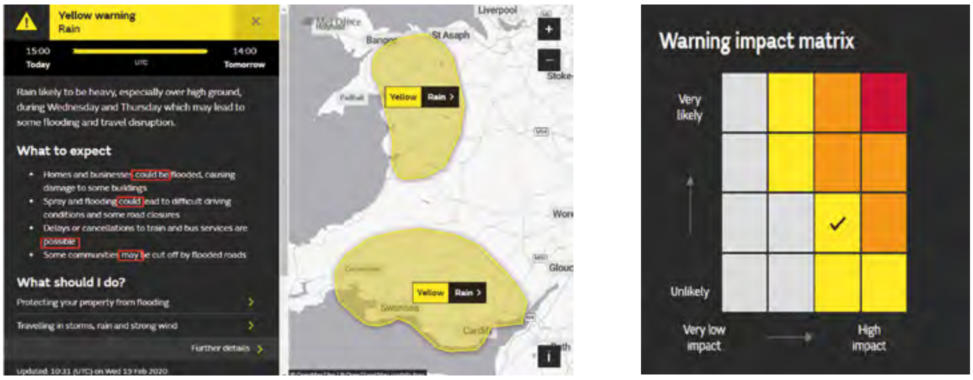


Figure 25. Excerpt from a UK Met Office Impact-based Weather Warning

Probabilistic language is used to describe the likelihood of specific impacts. The public weather warnings also indicate sectoral impacts for the given warning level.

Chapter 7. Accountability, Verification, Archive and Review

ARRCC Stakeholder Consultation Workshop in Nepal
Photo: RIMES/UK Met Office

Accountability

Impact-based forecasts and warnings have greater implications in terms of accountability, legally and politically, than traditional weather and climate forecasts.

As more organisations are involved in creating impact-based forecasts, accountability is shared across organisations. For example, the hydrological and meteorological services and partners have accountability, as the producers and issuers of forecasts and warnings to users; the government also has accountability, as the mandating and funding agency for the impact-based forecasting services.

Robust verification and review processes ensure producers of impact-based forecasts and warnings can justify any decisions taken during production and issuances, as well as identify areas to improve or maintain.

Verification

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.

Publicly publishing verification scores can help promote impact-based forecasts and warnings, by showing how well the tools perform and what changes and improvements are being made.

All components of an impact-based forecast and warning can be verified. However, it is not possible to judge an entire forecast system based on the results of a single forecast. A verification analysis should look at the performance of the impact-based forecasts over time. If forecasts are only starting to be produced now, "hindcasts" can be done to produce impact-based forecasts for historical events. Once there is a dataset of forecasts, the entire dataset can be verified together to give an indication of the skill of the system.

Table 8. Questions for Forecast 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 observed hazard magnitude different from the forecast hazard magnitude? Did this cause people to act “in vain” 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 other disaster impacts more relevant?	Observed impacts	▸ Post Disaster 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

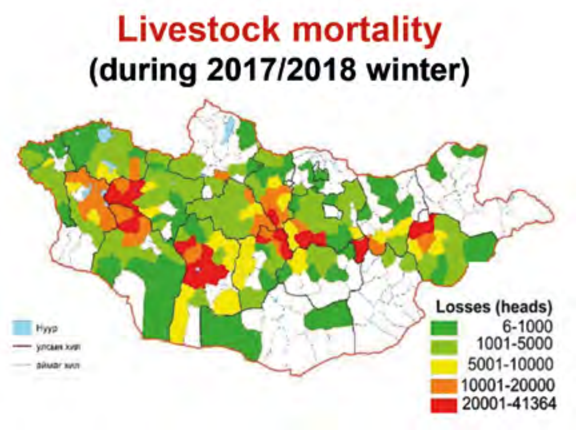
Component to verify	Questions to answer based on several forecasts	What verification information is needed	Sources of verification information
Forecast area of risk	Did the impact-based forecast and warning identify the area or locations at risk accurately?	Location of observed impacts Extent of area 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 users 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

Gathering impact information for verification

It is important to gather impact information from a range of sources, in a variety of formats. The most credible sources are reports and feedback from partners and organisations responsible for responding to crises. Agreements should be in place between partner organisations to record and share impact information. These agreements form part of a Memorandum of Understanding (MoU).

Reliable and credible impact information can verify warnings and forecasts and update vulnerability and exposure datasets. For example, observed livestock mortality figures in Mongolia have been used to verify impact-based forecasts both in forecasted mortality, but also forecasted area (Nandintsetseg et al. 2018).

Figure 26. Mongolia Livestock Mortality Map



Social media monitoring tools

Social media monitoring tools that search text, pictures and video content based on keywords, hashtags, locations and organisation or individual names, can be used to search for impact information. For example, photos of flooded areas or actions that have been taken to prepare for flooding.

Social media monitoring tools can also be used to assess the public perception of forecasts and warnings. Incorporating audience's sentiment from social media can improve impact-based forecasts and warnings.

510 Online News Scraper and Text Mining Tool

A news scraper can retrieve relevant impact data from online newspapers. The tool uses keywords provided by the user, such as 'floods' or 'Uganda.' To collect data, the 510 News Scraper and Text Mining Tool:

1. Searches articles for relevant data
2. Determines the relevance of the articles.
3. Outputs an impact database in a .csv file.

The results provide an alternative or complementary source of data to traditional event databases. This can be helpful in locations where historical data is scarce. Currently, this tool is used to improve humanitarian aid, but could be part of an impact-based forecast verification process.

Surveys and Feedback

Surveys after a weather or climate event can help establish how well impact-based forecasts and warnings performed.

National hydrological and meteorological services can use telemarketing, 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 national hydrological and meteorological services and partners.

Examples of verifying impact-based forecasts and warnings

- In the UK, the Met Office is given impact-based warning targets by the Department for Business, Energy, Innovation and Skills (BEIS): the government department to which the Met Office reports.

The Met Office Subjective Verification Process measures the effectiveness of impact-based warnings in the UK. Issuance of an amber or red impact-based warning triggers the process. Verification happens as soon as possible following an event. Assessors complete a verification form, which is subjective and includes a scoring system. The Subjective Assessment Panel collates and analyses these assessments, alongside assessments of forecast model performances. Then, the assessment report is presented to the BEIS for sign-off. The department may accept or dispute the report's findings. A final score is added to the performance assessment measures and any learning points are addressed through the weather warnings working group.

- The Australian Bureau of Meteorology conducts verification as part of Post Event Review Management using the process shown on the next page. The level of review varies depending on the severity of the impacts.

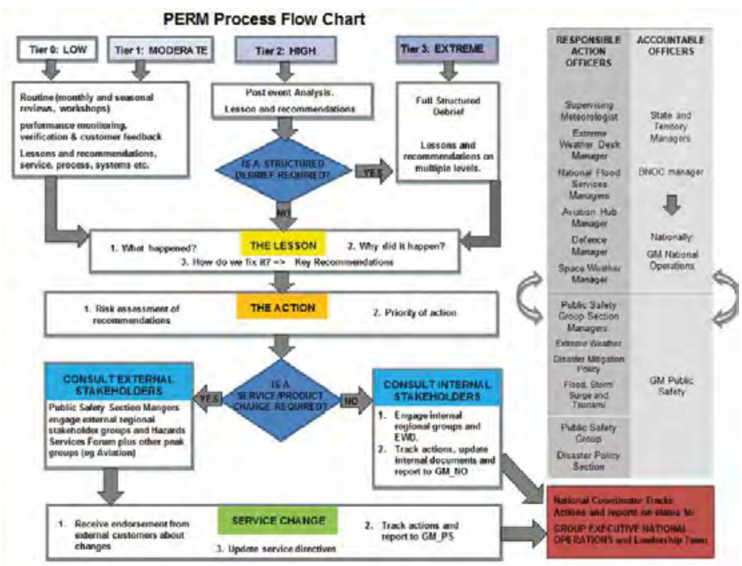


Figure 27. Australian Bureau of Meteorology - PERM Process Flowchart

Case study UK Subjective Verification Form (Form as of March 2015)

1. Warning Summary

Add details of the warning being assessed or, if no warning issued, add details of the medium or high impacts observed including the area and period over which they were observed for the purposes of assessing a potential "miss".

Issue Date/Time *(if warning issued)*			
Valid From *(or earliest time of observed impacts)*			
Valid Until *(or latest time of observed impacts)*			
Summary of the area of risk *(Give a brief summary of the area highlighted in the warnings or, if no warning was issued but medium or high impacts were observed, give details of the area(s) over which the impacts were observed)*			
Matrix Information *(Indicate in the boxes below where the tick appeared in the matrix of the warning. If no warning was issued give only the levels of impacts recorded.)*			
Likelihood *(VL, L, M, H)*		Impact *(VL, L, M, H)*	
Brief Summary of impacts observed *(Highlight some of the main impacts observed and provide an assessment of the level - very low, low, medium or high- of those impacts)*			

Other information *Please add any other comments you may wish to be taken into consideration when assessing this warning/event e.g. YLO warnings already in force and considered adequate at the time, discussions with FFC/SFFS/Advisors which influenced the issue, any discussions with other local agencies, government departments etc.*	

Now complete the assessment below. Only Section 2 counts towards the PWS target. Sections 3, 4 and 5 are noted for the purposes of continuous improvement both in terms of forecasting practice and service delivery.

2. Assessment of Issued Warning

If no AMBER or RED warning issued, consider any YELLOW warning in force at the time of the impacts. If no YELLOW warning either, then assign a total score below of "0" i.e. Very Poor Guidance

Impact Levels	
3	*Impact column ticked in warning is consistent with impacts experienced*
2	*Impact column ticked in warning is within one level of impacts experienced e.g. if warning indicated "medium" impacts while those experienced were "low"*
1	*Impact column ticked in warning is within two levels of impacts experienced e.g. if warning indicated "medium" impacts while those experienced were "very low"*
0	*Impacts were reported and no warning was issued or no impacts were reported.*
Comments as necessary *(Add any further information which influenced your marking)*	
Assessment Score for Area *(0,1,2 or 3)*	

Area Affected	
3	*All impacts noted were within the warning area.*
2	*The impacts occurred generally within the area indicated but the area is deemed to be too large or slightly too small*
1	*The area is generally displaced from the main impacts but a few impacts occurred within it*
0	*No warning was issued or there were no reported impacts in the area identified by the warning.*
Comments as necessary *(Add any further information which influenced your marking)*	
Assessment Score for Area *(0,1,2 or 3)*	

Validity Time	
3	*All the impacts were noted within the warning validity time and the warning was issued at least 2 hours before the start validity time*
2	*Most of the impacts occurred within the validity time while others were no more than 2 hours outside the period*
1	*Some of the impacts occurred within the validity time but most occurred within 2 hours either side of the period*
0	*No warning was issued or none of the impacts identified occurred within the validity time period.*
Comments as necessary *(Add any further information which influenced your marking)*	
Assessment Score for Validity Time *(0,1,2 or 3)*	

Total Score *(out of 9)*		
Overall Marking Assessment		
0-2	Very Poor	A missed warning or false alarm, i.e. either at least medium impacts were observed without any warning being in place, or a warning was in place but no impacts were observed.
3-5	Poor Guidance	A warning was issued, but it was either issued too late after the onset of the event, or the impact levels, area and/or validity time were significantly different to those observed so that the warning was of limited use to responders and the public.
6-7	Good Guidance	Generally the warning was of use to responders and the public, but could have provided more accuracy or usefulness in terms of impact levels, area covered, validity time and/or timeliness of issue.
8-9	Excellent Guidance	The impacts, area, and validity time of the warning were closely in line with what was observed, and the warning was issued in good time before the onset of the event.

3. Warning Issued more than 24 hours ahead?

Please note here if a warning was issued more than 24 hours ahead of the event. Although this is not formally part of the assessment process, information in this section may be used to inform overall marking decisions in marginal situations

Was an alert Issued more than 24 hours ahead?		**Yes/No?**
Comments as necessary *(Add any further information which you feel may be useful)*		

4. Wording of the Warning

Please assess and comment on the wording of the warning (both main section and Chief Forecaster's Assessment) so that feedback can be provided to Chiefs on good practice etc.

Wording of the Warning	
Very Good	*The wording of the warning was clear and very helpful to the reader with a good explanation of e.g. uncertainties, reasons for changes from previous issues etc.*
Good	*The wording of the warning was reasonably clear but some areas were identified which could have improved it*
Poor	*The wording might have caused some confusion to the reader and/or was too brief.*
Very Poor	*The wording of the warning was obscure or too technical and generally unhelpful to the reader*
Comments as necessary *(Add any further information which influenced your marking)*	
Assessment Score for Wording *(VG, G, P, VP)*	

5. Lessons Learned

Please summarise any learning points you feel come out of this warning either in relation to the issuing of the warning or in relation to its assessment.

Archives

Archives can be used to improve impact-based forecasts and to provide data for any inquiries. Additionally, creating an archive of impact-based forecasts and warnings and any related data should be considered. Forecast verification takes into account multiple forecasts and events, as the result from a single forecast error does not necessarily indicate the entire system is not useful.

Review

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. The verification process provides a mechanism for collating regular feedback from users. 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.

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