# A guide to trigger methodology for forecast-based financing

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New version - July 2018

# 1. Glossary

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|---|---|
| **Trigger** | A forecast that exceeds a predetermined probability and magnitude, which activates an intervention in a specific region at a specific lead time. |
| **Impact level** | The degree of forecasted loss and damage that would trigger action. If more than a predetermined probability of a certain amount of loss/damage is forecast, then we act. |
| **Forecast lead time** | Time between release of a forecast and the forecast hazard potentially occurring. |
| **Preparedness time or implementation time** | Time required to implement and complete the early action. |
| **Forecast** | A statement of expected meteorological and/or climate and/or impact conditions for a time and place. |
| **Forecast skill** | How well a forecast compares to the actual observation of what was predicted. |
| **Impact-based Forecasting** | A forecast of the potential consequences of a hydrometeorological event, in terms of its effects on people, infrastructure, etc. |

# 2. Rationale of this guide

This guide will outline the design process of an impact-based forecasting methodology to be used to define forecast-based financing (FbF) triggers. It is meant to support stakeholders involved in developing triggers and provides step-by-step instructions and examples on how to do this. This is a living document, based on ongoing projects; it will be periodically updated to include best practice and lessons learned. If you have suggestions, please email: fbf@climatecentre.org.

Firstly, lessons learned from pilots around the world are presented. Second, each of the steps to develop triggers will be explained in detail. The target audience is institutions and/or government agencies interested in developing impact-based forecasting systems to enable early action.

# 3. Lessons learned from first-phase FbF pilots

The first phase of FbF (2013–2017) focused on identifying an individual danger level for a specific geographical area and event (e.g. flood) and then triggering early action when a pre-identified forecast indicating an increased risk of occurrence at a certain confidence level. For example, in Bangladesh, when wind speeds were forecast to be above a certain strength in specific villages at a certain lead time, the Bangladesh Red Crescent Society would take action. However, there were several limitations with this original methodology:

1. *Using a single danger level based on only the hazard forecast*: In Bangladesh, low wind speeds might destroy houses made of thatch, while high wind speeds might destroy houses made from iron. In reality, there is no single danger level, just increasing impact as the hazard event becomes more extreme. Impacts also differ in areas with different vulnerability.

2. *Focusing on a single location*: While it would be good to be able to define a robust impact curve for every village in Bangladesh like was done in this pilot, monitoring and evaluation showed that doing so would be time and cost resource heavy. An ideal system would assess potential impact across an area of interest, e.g. identify areas at risk of disaster anywhere in the country. This would align with the way disaster

response teams currently operate – reacting to impact anywhere in their area of responsibility. In the FbF case, we would like to be ready to act wherever impact is forecast.

3. *Frequency of the trigger:* In order to anticipate how often we will take action, we need to estimate the frequency of receiving a triggering forecast. For example, a forecast saying that there is a 50 percent chance of a 1-in-2-year flood might be issued every year, but in only half of the years will there be a flood.

Based on these lessons, the FbF trigger methodology in Phase 2 is based on 'impact-based forecasting'.

# 4. Focusing on impact, instead of hazards

Impact-based forecasting[1] methodology focuses on what a hazard could *do* in terms of consequences rather than forecasting only what a hazard could *be*. FbF systems can support intervention in any locations forecast to experience severe humanitarian impact. 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). Achieving this requires national meteorological and hydrological services to work in partnership with other government agencies and actors.

FbF will support ongoing efforts in the delivery of climate services. This is perhaps one of the most difficult challenges to overcome, but through the FbF pilots many actors and stakeholders have coalesced.

**Why impact-based forecasting?**

*Impact-based forecasting provide information of how hazards may impact warning recipients – of what the weather can potentially do.*

- *National meteorological and hydrological services (NHMS) issue hazard warnings, yet populations suffer casualties and damage often because they do not realize what kind of damage to prepare for.*
- *An NHMS cannot deliver impact-based forecasting services on its own – a hazard forecast is combined with information on exposure and vulnerability to produce an impact forecast. This process of combining hazard, exposure, and vulnerability is 'impact modelling'.*
- *Creating systems to support impact warnings is based on close coordination between NMHS and organizations like government disaster and civil protection agencies.*

Developing FbF capability/readiness can help met services and disaster-management

[1] See *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services*.

agencies create the necessary partnerships and data-sharing arrangements. Sometimes hazards indirectly unrelated to weather can also cause flooding, such as dam discharges, and wider partnerships become necessary.

Impact-based forecasts translate meteorological and hydrological hazards into potential sector-specific and context-specific impacts. This can lead to the development of more efficient sectoral responses to mitigate those impacts at various levels, including potential at the household and institutional levels. By focusing on impacts and communicating them, it is expected that the population at risk and the responding professionals will have a better understanding of the risk and potential disruptions, which can be used to develop triggers to identify when and where to take appropriate early action.

For example, this map, developed by the International Research Institute for Climate and Society, shows the malaria transmission risk over Africa, using information about precipitation and temperature.

In an FbF system, action would be taken when a trigger is reached. The trigger happens when a pre-identified forecast product, at a certain lead time, indicates a sufficient probability of impact. This means that the forecast shows a sufficient probability that an extreme event (hazard) will happen in an area where a certain level of vulnerability exists. The hazard forecast is combined with the vulnerability and exposure layers to create an impact-based forecast output that will indicate where there is increased risk of different levels of impacts to different populations. If the result shows sufficient probability of impacts above a specific level then action should be taken. Different levels of forecast impact, at different lead-times, could trigger different types of action.

Lead times will vary according to the forecast used: observations (e.g. rainfall has already fallen), short-range weather forecasting (12 to 72 hours), medium-range weather forecasting (above 72 hours and up to 10 days), extended-range weather forecasting (up to 30 days), monthly, three monthly, and seasonal outlooks. Forecasts at different lead times tend to predict different variables (e.g. seasonal rainfall vs 3-day rainfall totals), and it is critical to understand the relationship between the forecast itself and the hazard of interest (e.g. floods).

Selecting a trigger will be based on the action that people would like to take. Based on this action, they can determine both (1) which forecasted impact is the most relevant level to intervene, and (2) what probability of this impact should be used to trigger action.

To determine the impact-based forecast, five steps must be taken, as indicated in Figure 1. The first two steps are to create a risk analysis and an inventory of forecasts. The third step defines hazard magnitudes. The fourth step creates an impact-based forecast by either combining the risk analysis with the forecasts using expert knowledge or using elementary or more advanced modelling and historical impact data; the fourth generates an impact-based forecasting intervention map.

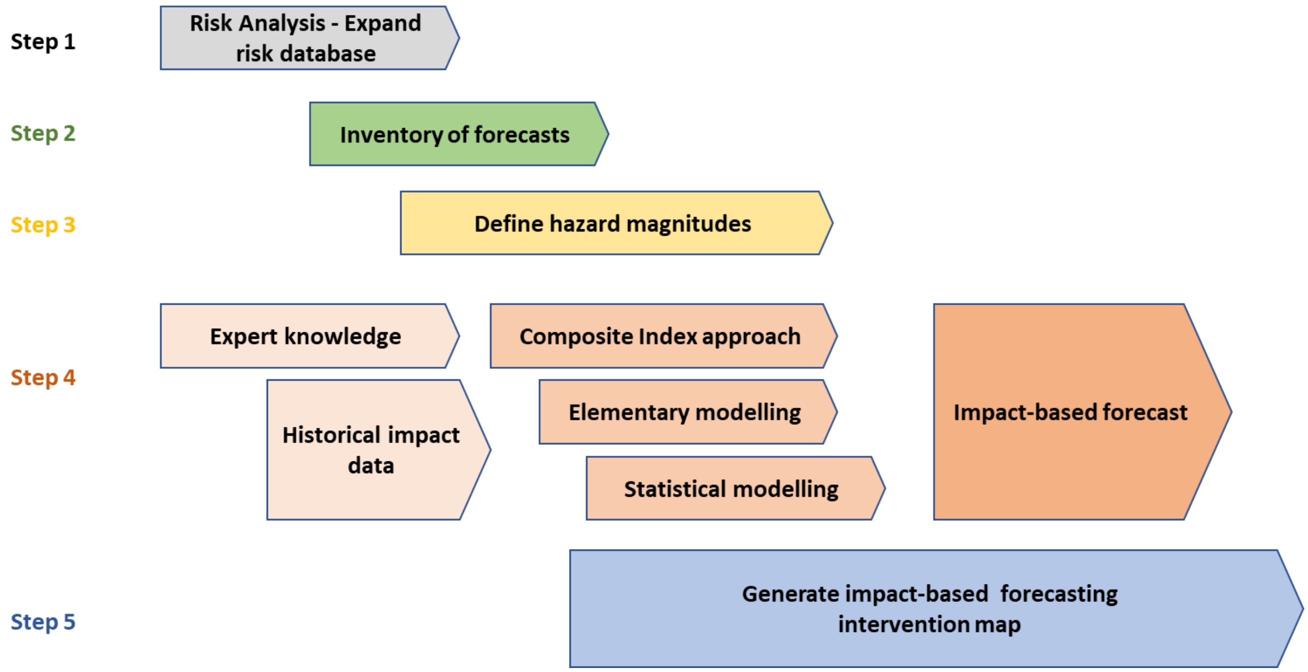



*Figure 1. Concept of Impact-based forecasting showing the five steps and the phasing.*

# 5. Who can implement this methodology?

The steps introduced here should involve all stakeholders in the forecast and risk analysis. Development of a multi-disciplinary working group is suggested to include all relevant stakeholders involved in the development, implementation and monitoring and evaluation activities. In the case there is a technical lead for the development of the trigger, specific steps could be researched and written up and the results presented to the working group. The stakeholders in the group can provide occasional feedback to the process and agree on the final recommended triggers (*see terms of reference of technical working group*). This methodology can be applied and adapted for floods, cyclones, droughts, cold waves, frost and heatwaves (potentially other hazards), however each hazard is unique and any potential adaptation should be discussed with the appropriate group of physical scientists.

Key actors to be considered for inclusion in the working group are communities, government agencies such as meteorological and hydrological services and others concerned with risk reduction and civil protection, the UN, National Societies, academic groups, and other national and international NGOs. Various suggested roles are outlined in the guide to early-action protocols.

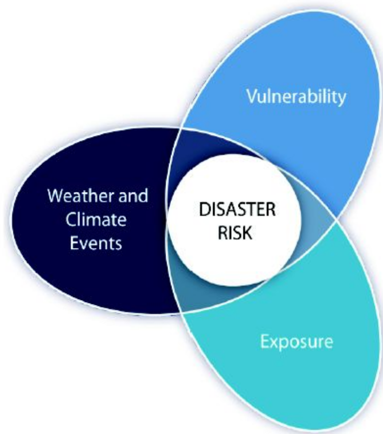
# 6. How to implement the trigger methodology

*The steps are not intended to be implemented in any particular order; different tasks may happen in parallel in what is an iterative process.*

***Step 1 – Risk analysis***

*Who is vulnerable to this hazard and where are they?*

The goal of a risk analysis, in the context of FbF methodology, is to understand through mapping and other methods what kinds of impacts can be expected from a particular type of hazard, and what types of vulnerability and exposure can combine with the hazard to cause impact.




For example, if damaged roofs from wind is a major impact of cyclones, an exposure map will indicate the geographical areas where houses are exposed to cyclones and a vulnerability map for cyclone wind and/or storm surge induced impact based on a composite of multiple indicators such as housing type, literacy rate, and remoteness will highlight the priority geographical areas. The overall hazard (e.g. a storm) should be separated into its "sub-hazards" (e.g. wind, rain, storm surge) to ensure that all exposed elements and their vulnerabilities are included.

A good starting point is to gather data on indicators for hazard, exposure, vulnerability and coping capacity. Existing national risk platforms, vulnerability and capacity assessments and other sources of data like the INFORM framework could be used.

These indicators can be narrowed down by concentrating on those most relevant for the specific hazard of interest. For example, building quality will be mapped for cyclones but not to droughts, while the indicator 'changes over time in school attendance" is a relevant vulnerability indicator for droughts but less so for cyclones. It is important to reach agreement among the key actors on these choices.

A specialized government agency or other experts in risk analysis and modelling should lead the implementation of this step, which should be agreed by the working group.

## 1. Hazard selection

The hazards to be tackled by the FbF system have already been decided during the feasibility study, based on historical impacts and forecast analysis (a simplified version of Step 2 in this guide).

## 2. Historical impacts

While it may be challenging to find quality information for some hazard types in certain areas, as detailed an analysis as possible of historical data on the impacts of the selected hazard is conducted. Key information would be the date of the event, its severity, and impacts on sectors like health, infrastructure, agriculture, food security, water.

This includes government data and other sources like past vulnerability assessments before disasters and needs assessments after them, DesInventar, EM-DAT, and news and social media.

This analysis will help the working group decide which impacts and exposure data will be used for the FbF trigger model. For example, after an analysis of cyclones impact in Mozambique with data from 1990, it was decided that the impact to be considered in the trigger model is the destruction of houses.

Key questions:

1. What is the historical database of the selected hazard? How confident are we in the quality of the historical records? What is the time and geographic distribution of impact for particular events? When did it happen? Where were the impact observed? What was the magnitude of the hazard? What were the impacts? How is the nature of the hazard expected to change in the future due to climate change, climate variability and other external drivers?
2. When a disaster happens, what are the vulnerabilities that lead to impacts? In which ways are people suffering most from the disaster? What in their daily lives is most difficult to deal with? Are their livelihoods jeopardized? Which sectors are affected the most? For example, a typhoon can cause human, material and crop losses through wind, sea surges, and floods and landslides inland.
3. What level of impact which can be tolerated by the population and infrastructure without generating any need for humanitarian intervention even at the local or national level?

## 3. Exposure analysis

This step determines the elements exposed to negative impacts due to the hazard and involves a description of population, infrastructure, natural resources, assets and other elements.

For this step, we use historical impact data, open sources, and official and non-governmental data; include details like access, sources, and quality of data, and the size of the administrative units it applies to (the smaller the better).

Next, we map the main exposed elements in the trigger model. For example, if the main impact due to floods is the *mortality* of children under five due to waterborne diseases, then the exposed element will be the *population of children under five*; or if it's damage to houses built of lightweight materials, then the exposed element will be *houses built with lightweight materials*; or (in Peru, for example) if the prioritized impact due to cold waves is the mortality of alpacas, then the exposed element will be the alpaca population.

Key questions:

> Which populations 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.

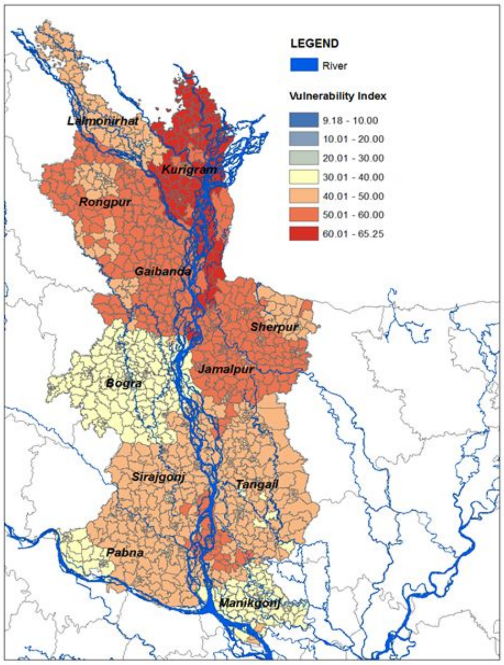
### 4. <u>Vulnerability analysis</u>

Here we identify and agree indicators of vulnerability – down to the smallest administrative unit possible – to be used in the trigger model. For example, if the mortality of children under five due to floods is the priority impact, the vulnerability indicators could be malnutrition, existing mortality and morbidity, and number of children per household. In some cases coping capacity can also be integrated into the trigger model.

Key questions:

1. 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 in people's ability to prepare for and cope with impact.
2. Which vulnerability indicators can be used in the trigger model? What is their quality? Are they at the same geographical scale? How often are they updated?
3. Which vulnerability indicators duplicate each other (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.




*Map 1. Composite vulnerability index for the Jamuna river basin, Bangladesh.*

### *Step 2 – Inventory of forecasts*

*What are the potential forecast products available? What is the most appropriate forecast product we can use? What are the mandates around using various products?*

An analysis of forecast verification, type, reliability, lead times, and sources of data for forecasts should be presented as an inventory, to allow the working group to decide which to use.

This should include:

1. Which *agency* produces it (NHMS, GloFAS, ECMWF, IRI, etc.).
2. *Type - how the forecast is produced.* Choices include observed data (e.g. gauged precipitation), statistical forecasts (e.g. extrapolation of an upstream river flow to a downstream location or an index based on El Niño sea-surface temperatures), and dynamic models (e.g. numerical weather-prediction systems and large-scale hydrological forecasting models).
3. *Format of Issuance. Deterministic:* Showing a single outcome without conveying potential error and uncertainty*, Probabilistic*: Showing the probabilities of one of more discrete outcomes or categories, *Intervals*: Showing an explicit upper and lower limit between which a value is expected to occur
4. *Frequency.* How often the forecast is produced.
5. Is the forecast generated by a computer *model* or produced by *human* estimates.
6. *Lead times. Time between forecast issuance and the beginning of the forecast target period.*

7. *Regions* covered.
8. *Skill* of the forecast & how the skill has been assessed, skill at a specific location, skill at predicting extreme events).
9. *Resolution* in space or time.

Once decision-makers make a choice of forecast, a more detailed skill assessment may well need to be carried out. Historical forecasts should be compared to historical observations and disasters to assess how often the trigger would be reached and the probability of 'acting in vain'. (Guidelines on forecast verification to come.)

| **Forecast** | **Sources /Availability** | **Forecast type/Spatial Resolution** | **Lead time *How often is produced)** | **Forecast skill** |
|---|---|---|---|---|
| **River flow** | SENAMHI | River flows forecast based on rainfall information of the ETA and WRF models (32 km and 22 km resolution respectively). Available at specific hydrological stations. | Daily for lead times up to 72 hours | Not verified |
| **River flow** | GLOFAS – JCR<br>Global Model<br>Daily bias correction by SENAMHI | River flows forecast and return periods based on probabilistic outputs of ECMWF IFS at ~10 km grid scale representation of the river, bias corrected using daily observations | Daily for lead times up to 45 days | Verified 9 days lead time<br>45% chance of false alarms for a forecast of exceeding the 1-in-10 year return period |
| **River flow** | Deltares<br>Global Model | River flows forecast and return periods based in probabilistic outputs of delayed ECMWF forecasts and GFS at the level of hydrological stations | Daily for lead times up to 10 days | Not available due to lack of data for verification |
| **River flow** | GLOFAS – JCR<br>Global Model | River flows forecast and return periods based in probabilistic outputs of ECMWF at the level of hydrological stations | Produced every season for the following 3 months | Available from GloFAS team |
| **River Level** | SENAMHI | Forecast trend based on the statistical model at the Enapu station - Iquitos. | Produced every season for the following 3 months | Not available due to lack of data for verification |

*Table 1. Example of inventory of forecast for river floods in the Amazon. Note: The inventory of forecasts do not necessarily need to include all of the forecast attributes stated above and in that given format.*

*Step 3 – Define hazard magnitudes*

*What magnitudes of hazard could happen?*

For impact-based forecasting, the main focus is on high-impact hazards: heatwaves, cold waves, extreme precipitation, tropical cyclones, floods and drought. In this step, past hydrometeorological data should be gathered, enabling a picture of the climate to be built. This historical data is use to build a "climatology" providing a unique distribution for each grid cell or observation point, allowing us to understand the past magnitudes of the hazard location by location.

This climatology can be used to generate return period maps commonly used to explain the probability of an extreme event happening in a given year. However, they can be misinterpreted: The correct definition of a 5-year rainfall event (for example) is the amount of rainfall that has a 20 per cent chance of being exceeded in any given year. It is entirely possible to observe a one-in-five year event in two consecutive years, or even in the same year.

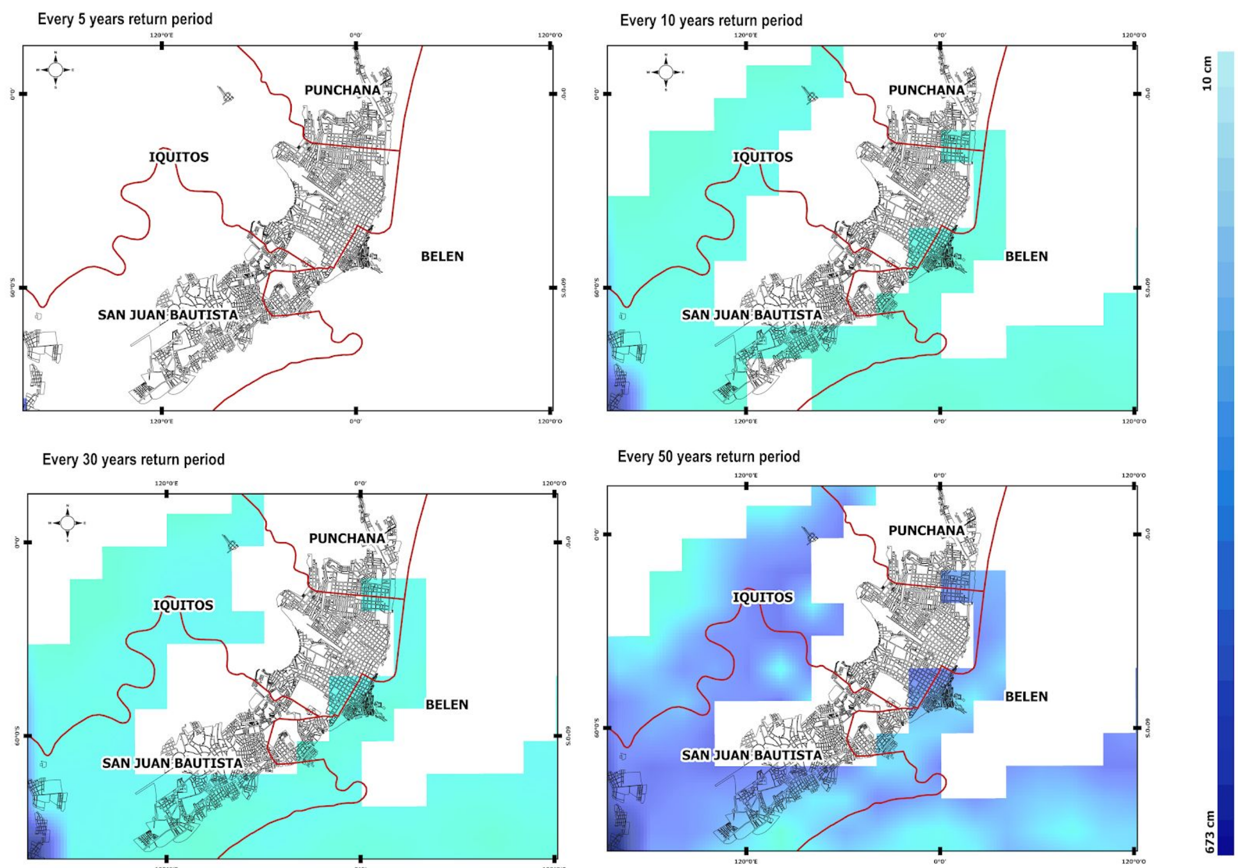



*Figure 2. Return period maps – showing distribution of inundated area (not necessarily impact on people) for events at increasingly rare occurrence levels – related to magnitude of inundation.*

*Step 4 – Analyse links between hazard magnitude and impact*

*What impacts can we expect from big or small hazards?*

This step – based on inputs from the previous steps – defines the relationship between impact and hazard magnitude that will be different for people of different vulnerabilities. Often called the impact-hazard curve or vulnerability function,[2] it establishes which impact can be expected given specific hazards and vulnerabilities, and it needs to be established for sectors, impact types, countries and/or regions.

Complexity depends on data. For example, if the major impacts of a given hazard are in the health and agricultural sectors, then impact curves in the context of FbF should be done for each. In places with very little data, the 'curve' could just be a deterministic statement such as: "At 100 kph we expect 20 per cent of houses to be destroyed, and at 150 kph we expect all houses to be destroyed."

At its most basic, impact curve development would rely on expert knowledge and qualitative categories rather than quantitative data from historical disasters. For instance, in the case of flood risk, this may involve water managers, irrigation experts and dam operators as well as disaster managers, DRR and hydrometeorological experts and others. The information can be created in a general sense for an entire region (river basin, coastal area, etc.), or be more geographically specific and targeted to groups, factoring in considerations like the timing of the events. However, the impact risk sensitivity conditioned on timing of the hazard will be different depending on the area of interest. For example, some areas have more extreme socioeconomic hourly shifts in activity – big cities may have more extreme rush hour periods than smaller cities and rural areas.

It is also important to understand, if data allows, how vulnerability and exposure have changed over time.

This step should provide decision-makers with a view of what impact can be expected for which people (or livestock/assets) at which magnitude; the next will provide an idea of the geography involved.

**Approaches to impact-hazard curves**

1. *Expert knowledge / the composite index*

This approach uses the expert judgement of people who work in the region and have an understanding of what kind of impacts can be expected when a hazard strikes. For example, experts can indicate that above 100km/hr winds, 20% of houses are likely to be

[2] GFDRR: A vulnerability function is an analytical or empirical expression that relates the building damage to a hazard intensity measurement.

destroyed, and above 150km/hr winds, all houses are likely to be destroyed. This expert view can be combined with a map of vulnerability information, to identify the most vulnerable administrative area for early action according to budget available.

**Monitoring and Trigger Matrix**

| | | | | | | Monthly Monitoring | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Indicator Group | N. | Indicator | Threshold | Source | Weighted Value | Indicator Available (Yes=1; No=0) | Threshold surpassed (Yes=1; No=0) | Result | Max | Relative Score by group |
| Vulnerability | | | | | | 1 | 1 | 0 | 3 | 0% |
| | | | | | | 1 | 1 | 0 | 3 | |
| Forecast (hazard & exposure) | | | | | | | | | | |
| | | | | | | | | | | |
| Coping capacity | | | N/a (considered a constant value) | | | | | | | |
| | | | Total | | 0 | | | 0 | 6 | |
| | | | | | | | | | TRIGGERING SCORE | |

| Decision Making Guidelines | |
|---|---|
| Potential Levels | Actions to be taken |
| **Monitoring** Only between 0 and 40% of triggering score | 1) Continue monitoring; 2)Share update of monitoring results with sector partners and discuss findings; |
| **Assessment** Between 40 to 60% of triggering score | 1) Call for partners meeting; 2) Immediate review of qualitative references; 3)Send field assessment within a week; 4) Based on outcome, decide either for launching preparedness actions, developing |
| **Action** More than 60% of the triggering score | 1) Contact Immediately HQ Team for Monitoring support; 2) In parallel, call for partners meeting and send field assessment within 4 days; 3) Within 10 days, decide if launching preparedness actions or developing EA Proposal |
| **Additional qualitative references for interpretation** | |

*Figure 3. A monitoring and trigger matrix that can be used for the composite index approach.*

When experts can relate hazards (e.g. 100km/hr) to absolute levels of impact (e.g. specific houses destroyed), this implies making assumptions and it becomes especially difficult to base the expected impact on more than one indicator – not only on hazard magnitude but also on vulnerability indicators. Predictions of absolute impact levels can instead use historical quantitative data and not expert judgement. This is where the following approaches come in.

2. *Elementary modelling*

Historical data from observations (as opposed to modelling) can point to the relationship between hazard magnitudes and vulnerabilities. A good example of this approach is the one used in the FbF project in Uganda. Impact data was collected, which recorded when there was impact of floods in the last couple of years. This was compared with forecasted water discharge levels for each day during those same years. A relationship was determined which best discriminated the impact periods, from the non-impact periods. In this case, the project did not develop a full hazard-impact curve but selected a single level above which they determined there was significant impact.

This is the simplest relationship that can be established. It only establishes a correlation with one indicator (water discharge) and distinguishes two levels of impact: flood or no flood. Instead, this approach can be expanded to allow for different levels of impact and establish separate relationships for different levels of vulnerabilities. This could, for example, produce a chart like Figure 4. (Quantitative modelling should be adjusted by experts.)

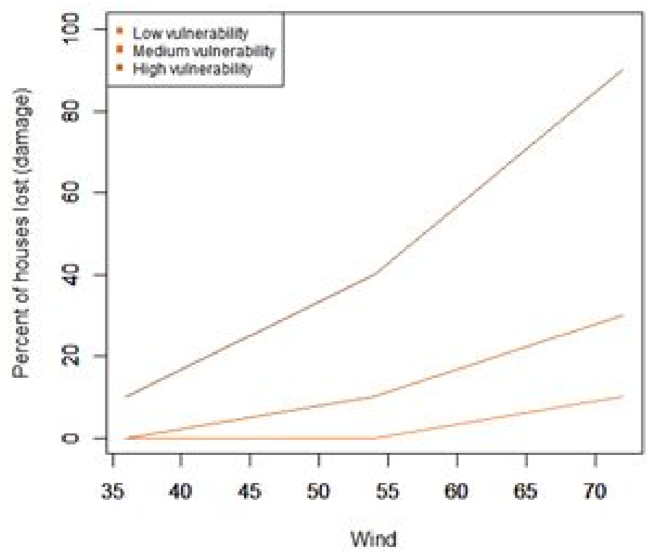



*Figure 4. Example of impact curve based on wind speed in knots and vulnerability (low, medium and high).*

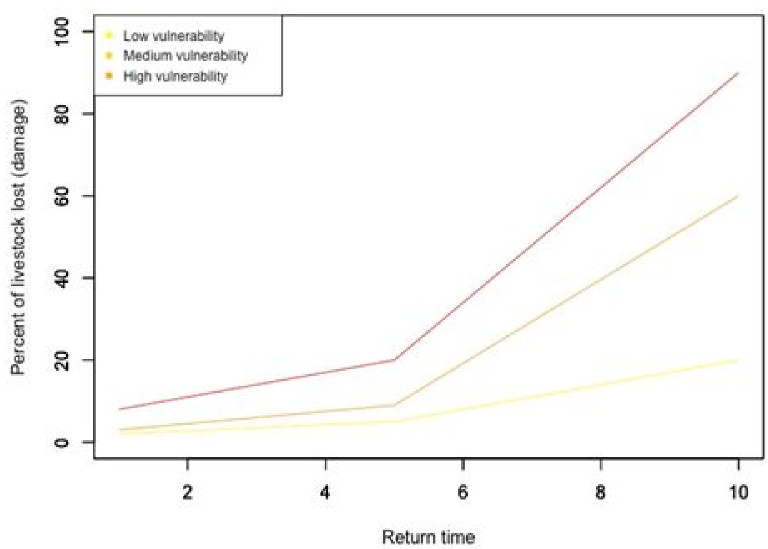



*Figure 5. Example of impact curve based on livestock lost and vulnerability (low, medium and high vs return period (years).*

Note that it requires data quality and access to establish such a chart, and the results should be verified against new data or expert judgement to ensure they make sense. From here, it is then only a small step to a formal statistical model.

*3. Statistical modelling*

Statistical modelling and machine learning, based on good impact data for historical hazards, test the potential of several explanatory indicators. These tools can create more complex relationships between the input information (e.g. vulnerability, hazard, exposure), and the predicted impacts. Impact differences between urban and rural areas might be explained through a statistical model of differences based on short-term forecast variables and others covering vulnerability and capacity. Crop models for agro-hydrometeorological forecasting are one example from the complex end of the spectrum.

Ultimately, whichever of these three approaches is used, the resulting model will give decision- makers perspective on which impact – in absolute or relative terms, and comparing municipalities or other administrative levels – can be expected for a given magnitude of hazard and vulnerabilities.

In the next step, this model becomes a concrete output for decision-makers planning if and where to implement early actions.

*Machine Learning is an algorithm that can learn from data without relying on rules-based programming.*
*Statistical Modelling is formalization of relationships between variables in the form of mathematical equations.*

### ***Step 5 – Generate impact-based forecast intervention map***

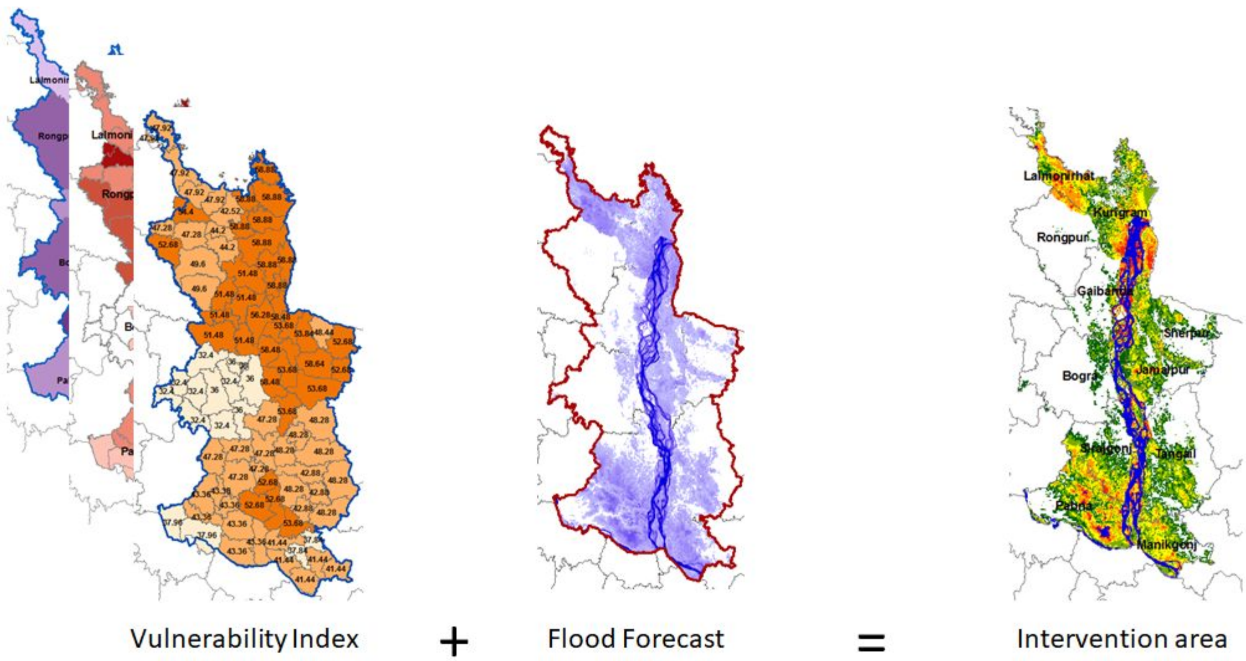
*Where and when should decision-makers carry out early actions?*

In this last step, we combine vulnerability and exposure information with the real-time forecast (from the inventory of forecast, hazards magnitude analysis and the analysis of impact level) to identify which areas are likely to be most impacted. Often, vulnerability and exposure maps have been used primarily for planning and infrastructure but not routinely to contextualize forecasts and warnings.

There are two main ways to do this. First, the most advanced form would digitally combine the forecast, vulnerability and exposure maps or data within a time-dependent model, to forecast the evolving situation. This approach can target priority areas for early action to be able to reach the most at risk communities effectively before the event happen. This first option will provide a map-based tool or a list of prioritized districts, municipalities or other geographical areas where the early actions will be activated.

However, in a second approach, at its simplest, vulnerability and exposure information can be combined qualitatively with forecasts to produce qualitative statements about impacts.

IT capacity will vary between agencies and the design of tools needs to take this into account. Likewise, forecast skill and stakeholder engagement will also vary, but can be expected to improve with engagement in the FbF process over time.




*Map 2. Impact-based forecast intervention map in the Jamuna river basin, Bangladesh. This graphic shows a final potential product (map intervention area – step 5) that is created based on the detailed risk analysis (step 1) and impact forecast analysis (step 2, 3 and 4)*

## Acknowledgement

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*We would appreciate any feedback, examples, or suggestions you would like to provide. Please email fbf@climatecentre.org.*