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The **Associated Programme on Flood Management** (APFM) is a joint initiative of the World Meteorological Organization (WMO) and the Global Water Partnership (GWP).

It promotes the concept of Integrated Flood Management (IFM) as a new approach to flood management. The programme is financially supported by the governments of Japan, Switzerland and Germany.

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To the reader

This publication is part of the *"Flood Management Tools Series"* being compiled by the Associated Programme on Flood Management. The *"Flood Forecasting and Early Warning"* Tool is based on available literature, and draws findings from relevant works wherever possible.

This Tool addresses the needs of practitioners and allows them to easily access relevant guidance materials. The Tool is considered as a resource guide/material for practitioners and not an academic paper. References used are mostly available on the Internet and hyperlinks are provided in the *References* section.

This Tool is a *"living document"* and will be updated based on sharing of experiences with its readers. The Associated Programme on Flood Management encourages disaster managers and related experts engaged in flood forecasting and early warning around the globe to participate in the enrichment of the Tool. For this purpose, **comments and other inputs are cordially invited**. Authorship and contributions would be appropriately acknowledged. Please kindly submit your inputs to the following email address: apfm@wmo.int under Subject: *"Flood Forecasting and Early Warning"*.

Acknowledgements

This tool makes use of the work of many organizations and experts as listed in the references. We would like to acknowledge the members of the Climate and Water Department at WMO along with the members of the Technical Support Unit of the APFM who contributed competent technical guidance and frank discussions on the issues and who brought various perspectives into focus.

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1 INTRODUCTION

1.1 Background

1 Regular floods are part of people's lives in various regions of the world, recurring with varying magnitudes and frequencies to which people have adapted for centuries. These floods are generally expected and welcomed in many parts of the world, since they enrich the soil and provide both water and livelihoods. In contrast, flooding resulting from extreme hydro-meteorological events and occurring in unexpected magnitudes and frequencies can cause loss of lives, livelihoods and infrastructure. They can also damage the environment.

2 Floods have the greatest potential for damage of all natural disasters worldwide and affect the greatest number of people. Globally, there is evidence that the number of people affected by flooding is on the rise at an alarming rate, with associated economic damage. Floods are becoming more frequent, more intense and less predictable for local communities. The *Fourth Assessment Report* (2007) of the Intergovernmental Panel on Climate Change (IPCC) predicts that *"heavy precipitation events, which are very likely to increase in frequency, will augment flood risk"*. These floods will affect life and livelihoods in human settlements in all areas, such as flood plains, coastal zones, river deltas and mountains. Flooding is also increasing in urban areas, causing severe problems for poor and vulnerable people.

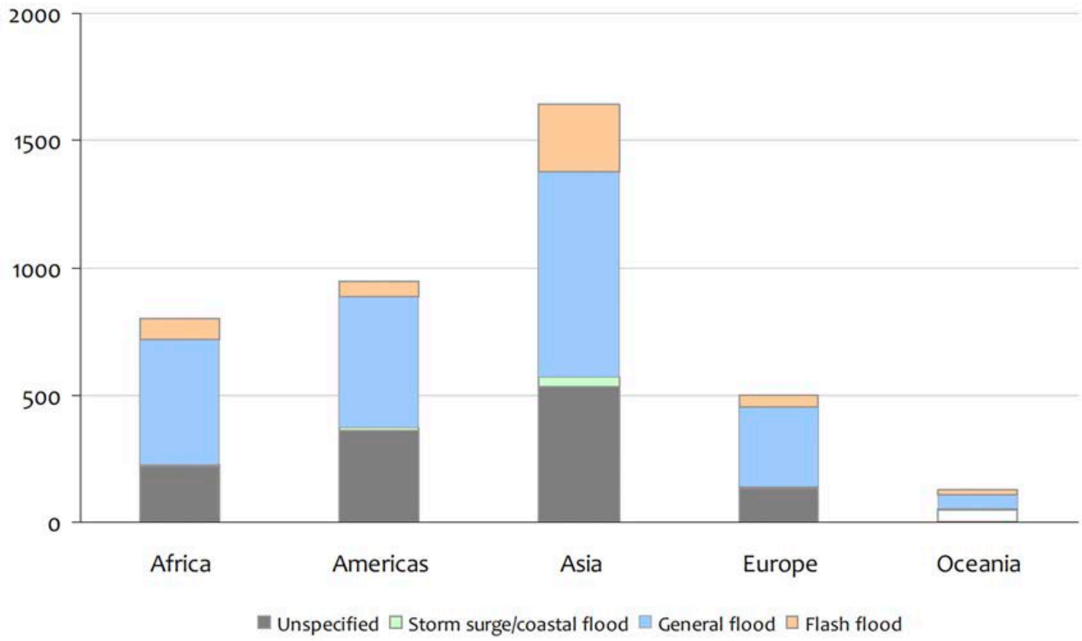

Figure 1 — Global floods events from 1900-2011
(Source: EM-DAT, The OFDA/CRED International Disaster Database, www.em-dat.net
Université Catholique de Louvain, Brussels, Belgium, created on July 13 2012. Data version: v12.07)

3 Floods are among the most frequently-occurring and deadly of natural phenomena, affecting an average 520 million people a year.[1] In recent decades, almost half the people killed as a result of natural disasters have been victims of floods, which also account for about one-third of economic losses from these disasters worldwide. Nonetheless, floods are also often part of nature's pattern: they carry nutrients that fertilize flood plains, and these plains are the spawning ground for many species of fish. The problem is to reduce human vulnerability to the negative effects of flooding while maintaining its helpful effects on the environment.

4 Flood risk is increasing over time as a result of population pressure in flood-prone areas, and the value of properties and infrastructure in these areas is increasing as well. Other risk drivers include climate change and variability, so policy makers need to examine how their decision making has to change in light of changing risk profiles. Information about existing models for accounting for climate change at different scales needs to be central to all decision making, along with understanding the uncertainties associated with those models.

5 Human settlements can be flooded by flooding rivers, coastal floods, pluvial and ground water floods, as well as by artificial system failures. Floods are typically the result of a complex of causes issuing from a combination of meteorological and hydrological extremes such as extreme precipitation and increased water flows. However, flooding frequently occurs as a result of anthropogenic activities including unplanned growth and development in floodplains or from a dam or embankment giving way.

6 Flooding is a manageable hazard where flood risk can be defined and appropriate emergency preparedness and mitigation strategies developed. However, the possibility of totally controlling

1 Disaster Preparedness and Mitigation, UNESCO, 2007

floods is a myth, with total flood protection or management a surreal concept. Floods occur in some areas according to a regular seasonal rhythm, the location of the flood is predictable, and there is usually some warning before they occur. Much can be known in advance about flooding and its consequences, so it is often possible to determine who will be affected and anticipate the problems they will face.

7 Many measures have been devised to help communities adjust to flood hazards and reduce the negative impacts of flooding. These have included structural and non-structural measures for both the long and the short terms. Of non-structural measures, flood forecasting and early warning have proved to be efficient and cost effective for minimizing the negative impacts of floods, often making the difference between life and death.

8 Early warning is important for saving lives and property from natural disasters in general and for providing information to facilitate evacuation from floodplains in particular. By giving sufficient advance notice in a clear and informative manner, the damage from disasters can be mitigated considerably. Co-operation among governments, national meteorological and hydrological services (NMHSs) and local communities is necessary. The warning recipients should be trained to adapt to such situations well in advance. Raising awareness and improving preparedness are essential factors in making non-structural measures more efficient.

1.2 Scope and Content of the Tool

9 The purpose of flood warning is to give advice about impending flooding so that people can act to minimize the flood's negative impacts. Some people will action on their own, while others will act as part their responsibilities within relevant agencies. Flood warnings are deemed effective if they help agencies play their roles efficiently during floods and if they persuade community members to act to lessen undesirable flood impacts.

10 This tool is designed to provide a practical, step-by-step guide to developing and operating the total flood warning system to agencies responsible for creating and communicating flood warnings. It covers predicting flood levels and the likely impacts of a flood, designing and disseminating warning messages, as well as the means of reviewing the system's effectiveness following an event.

11 It has been prepared to guide flood managers and can be used before, during and after emergencies. It is intended to help decision-makers establish an effective overview of the situation and find answers to their questions quickly. Many countries have already begun to incorporate flood forecasting and early warning in local and national emergency planning systems, and this tool is meant to provide information on developing flood forecasting and early warning schemes to help with this.

In particular, the tool aims to:

- Provide basic information about flood forecasting and early warning, focusing specifically on riverine floods;
- Identify flood forecasting and early warning components necessary to address flood risks;

– Provide perspectives on flood forecasting and early warning strategies that are important for planning flood management activities; and
– Provide guidance for involving local communities and individuals in flood forecasting and early warning.

12 Target groups for the tool are flood managers in governmental organizations at national, provincial and local levels, including National Hydrological and Meteorological Services and crisis service departments for improving flood forecasting and warning systems. This tool is largely based on the *Manual on Flood Forecasting and Warning* (WMO No. 1072), which was prepared and published by World Meteorological Organization in 2011. The tool uses terms and definitions that are included in the UNESCO/WMO *International Glossary of Hydrology* (WMO/UNESCO, 2012). Flood forecasting and warning can contribute to integrated flood management (IFM) by addressing two objectives: a) reducing the loss of lives by facilitating timely evacuation, and b) maximizing the net benefits that can be gained by the reducing losses and optimizing the use of floodwater (reservoir operation, replenishment/recharge of groundwater aquifer).

13 This tool has been divided into five chapters outlined below. Each chapter addresses a specific element of flood forecasting and early warning systems.

1.3 The Role of Flood Forecasting in Flood Management

14 Providing flood forecasting is a part of flood management planning and development strategies. These strategies address occupied flood plain areas where non-structural measures can be effective, for example temporary defences such as flood gates or movable barriers, or domestic protection such as sandbagging, as well as local evacuation to flood shelters.

15 Flood management requires engaging water management agencies and local or municipal authorities, along with transport and communications operations and emergency services. Flood forecasting has to provide information to these users so they can prepare and respond. In extreme cases flood forecasting is part of a wider disaster management capacity devolving from the highest level of government. The precise role of flood forecasting will vary according to the circumstances dictated by both the hydro-meteorological environment and the built-up environment.

1.4 Fundamental Considerations in Flood Forecasting and Early Warning

16 To form an effective, real-time flood forecasting system, the basic structures need to be connected in an organized manner. This requires: (a) providing specific rainfall forecasts (both quantity and timing) using numerical weather-prediction models; (b) establishing a network of manual or automatic hydrometric stations linked to a central control by some form of telemetry; and (c) flood forecasting model software connected to the observing network and operating in real time.

17 Flood warnings are distinct from forecasts since they are issued when an event is imminent or already occurring. Flood warnings must be issued to a range of users and for various purposes. These purposes include: (a) readying operational teams and emergency personnel; (b) warning the public of the timing and location of the event; (c) warning of the likely impacts on roads, dwellings and flood defence structures, among others; (d) giving individuals and organizations time to prepare; (e) in extreme cases, to enable preparation for undertaking evacuation and emergency procedures.

1.4.1 Meteorological and Hydrological Considerations

18 Clearly the ability to forecast critical events in time, location and quantity is significantly valuable for flood forecasting and warning. Meteorological knowledge associated with flood warning falls into two broad areas, namely the climatology behind flooding and the operational meteorology involved. Understanding the types of weather systems from which flooding can originate contributes a great deal to making decisions about what sort of observational and forecast systems are required. Similarly, understanding the seasonality of rain-bearing systems such as monsoons in Asia and tropical storms in Africa and Central America is also operationally important since this understanding will affect staff assignments and the organization of alert and background working patterns.

19 Hydro-meteorological statistics (primarily rainfall but also evaporation) are vital to flood forecasting and warning operations. They are usually dealt with by themselves, apart from climatology data. Hydro-meteorological data are also required in real time for providing flood forecasts and warnings. This has three aims: (a) to allow staff to monitor the situation in general terms; (b) to give warnings against indicator or trigger levels for rainfall intensity and/or accumulation; and (c) to provide inputs to forecast models, particularly for rainfall–runoff models.

20 Hydrological information requirements for flood forecasting and warning systems are similar to those for meteorology in that it is necessary to understand the overall flood characteristics of the area as well as possessing real-time information for operations. Key observation and data requirements target water levels in lakes and rivers, river discharge and in some cases groundwater table levels. Water level ranges at given points can be linked to various flooding extents, so a series of triggers can be set up to provide warning through telemetry. The upstream-downstream relationship between water levels is an important means of prediction. Early flood warning systems depend on comparing levels from a point upstream with resulting levels at a point of interest at the flood-risk site. It is also important to know the time it takes for water at a peak upstream to reach a point farther downstream.

1.4.2 Nature of Risks and Impacts

21 Flood risks are related to hydrological uncertainties, which are inextricably linked to social, economic and political uncertainties. Flood-risk management consists of systematic actions in a cycle of preparedness, response and recovery and should form a part of Integrated Water Resources Management (IWRM). Risk management calls for identifying, assessing and minimizing risk, or eliminating unacceptable risks through appropriate policies and practices.

22 The magnitude of flood events and impacts is variable, so flood forecasting and warning has to operate over a range of event magnitudes. Defensive and remedial measures are designed to operate up to a particular level of flooding severity having a particular level of probability. These measures reflect economic decisions balancing costs against losses. Typical design considerations cover a 100 years return period for urban areas with key infrastructure, 50 years for lesser population centres and transport facilities and 20 years for rural areas and minor protection structures.

1.4.3 Institutional and Legal Aspects

23 A flood forecasting and warning system needs to have clearly defined roles and responsibilities for the concerned institutions. Operating authorities may have permissive powers but not a statutory duty to carry out or maintain flood defence works in the public interest. However, such responsibilities may be incorporated in the legislative acts and regulations under which various government departments operate. Regarding legislation, it is therefore important that the interfaces between the duties and obligations of affected departments are carefully considered before statutory instruments are introduced.

24 Institutional structures and responsibilities may be complicated and may vary from country to country. In some countries, such as the United Kingdom, Bangladesh and Papua New Guinea, flood forecasting and warning systems are relatively complex and involve relatively large numbers of institutions. In contrast, Russia, Iceland, Nepal, some Eastern European countries and others have combined hydrological and meteorological services. In theory this eases data collection, use and dissemination issues that arise when one organization collects atmospheric data and others provide data on rainfall and rivers.

25 In the United Kingdom, France and other European countries, response has focused on flood defence and warning based on general meteorological severe weather forecasting. However, the occurrence of a number of severe events from 1995 to 2003 led to setting up national flood forecasting and warning centres in these countries. This has facilitated enhanced development of monitoring networks for flood forecasting and warning.

26 In many countries, governments or international agencies have no legal obligation to assist rebuilding or provide compensation to flood victims. Insurance is increasingly fulfilling this role in recovery, particularly in developed countries that have commercial arrangements. However, the increasing use of insurance has meant that when events occur, the cost to insurance companies is larger, leading to a rise in premiums. Insurance companies decide what is a worthwhile risk in their own terms, often making properties in high-flood-risk areas uninsurable.

2 ASPECTS OF FLOOD FORECASTING AND EARLY WARNING SYSTEMS

2.1 Introduction

27 Establishing a viable flood forecasting and warning system for communities at risk requires a combination of data, forecast tools, and trained forecasters. A flood forecast system must provide sufficient lead time for communities to respond. Increasing this lead time enhances the potential for limiting damages and loss of life. Forecasts must be sufficiently accurate to promote community confidence so that they will respond when warned. If forecasts are inaccurate, the credibility of the programme will be questioned and there will be no response.

28 Implementing an end-to-end flood forecast, warning and response system has many components, and these components must be linked in order to operate successfully. Their interaction may be represented as a multi-linked chain, with each link present and functioning if there are to be benefits. **Figure 2** is such a schematic representation of an integrated flood forecasting system within IWRM.

29 The essential components of a flood forecasting, warning and response system consist of a data source, communications, forecasts, decision support, notification (often referred to as dissemination), coordination, and actions (or responses). A flood forecast and warning programme should be designed to mitigate floods and is an asset to overall water management. All of the components of the system must therefore be functional. If any component is dysfunctional it becomes a weak link in the chain, undermining effective warning and response.

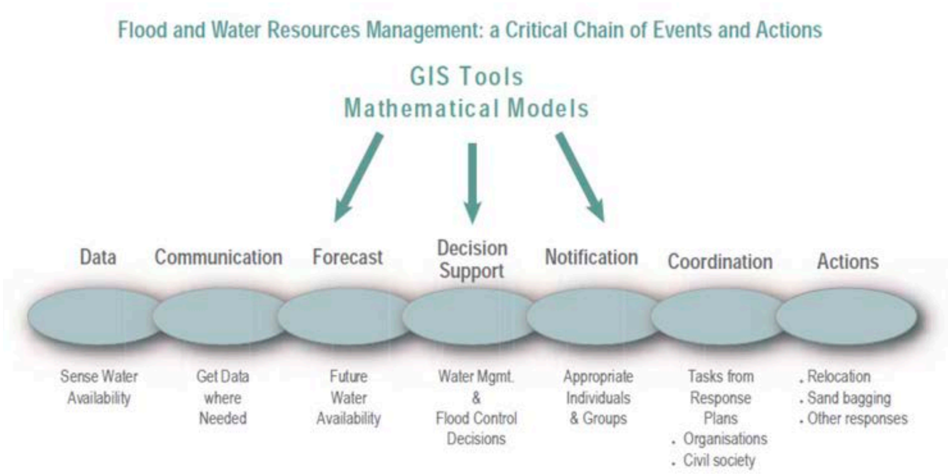

Figure 2 — Integrated flood forecasting, warning and response system within IWRM (UN, 2002)

2.2 Elements of Flood Forecasting and Early Warning System

30 An important element in developing flood warning systems is ensuring its robustness so that it can cope with the range of potential events. Flooding is a phenomenon subject to a wide variability of scale and severity. Flood warning systems must, therefore, be designed to forecast rare and severe events as well as less serious and more common ones. However, the uncertainties inherent in forecasting are likely to be magnified during extreme events and such scientific and technological limitations must be taken into account.

31 In 2006 the United Nations released its Global Survey of Early Warning Systems, which identified four elements in natural hazard early warning systems, including flood forecasting:

- i Risk knowledge: systematic assessment of hazards and vulnerabilities, including mapping of their patterns and trends;
- ii Monitoring and warning services: accurate and timely forecasting of hazards using reliable, scientific methods and technologies;
- iii Dissemination and communication: clear and timely distribution of warnings to all those at risk;
- iv Response capability: national and local capacities providing knowledge about how to act correctly when warnings are communicated,

2.2.1 Basic Considerations

32 To design a suitable flood forecasting service, it is necessary to understand:

- i The hydro-morphological characteristics of the basin topography, geology and soils, and the degree of structural development;
- ii The main physical processes occurring during hydro meteorological events; and
- iii The type of service that is required and that can be achieved technically and economically.

2.2.2 Types of River Basin

33 Every river basin has its own flood characteristics and behaviours. It is possible in general to define five main types of basin according to their temporal and spatial responses to a hydro. meteorological event **(Table 1)**:

Table 1 — Types of river basins

S N	Types	Size	Response time	Characteristics
a	Urban basins	Very small (a few km^2)	One or two hours	Densely populated and have a high proportion of impermeable surfaces that overwhelm the capacity of the drainage network
b	Upper watersheds and small to medium catchments	Between 10 and 500 km^2	A few hours	Upland areas and with steep slopes that react quickly
c	Medium-sized rivers	Between 500 and 10 000 km^2	Days to weeks (reflects major seasonal meteorological conditions)	Long-distance flow propagation with varying contribution of tributaries
d	The very specific domain of estuaries		Several hours (depending on the length of the fluvial upstream reach)	Combined influence of maritime storm surge, tide effects and upstream incoming flood and strong wind
e	Groundwater-controlled river systems		Long-duration flooding, lasting several weeks in some cases	Long, periodic fluctuations of the water table

2.2.3 Physical processes

34 The nature of any forecasting service is primarily dependent on the types of flooding occurring in the basin. **Table 2** illustrates these processes and shows that any one service may need to accommodate a range of basin types.

Table 2 — Physical processes of floodings

Physical influence	Wind	Infiltration	Rainfall intensity	Run off	Propagation	Tide and surge	Water table
Type of basin							
Urban		+	+++	+++	+		
Upper basin		++	++	+++	+		
Long river	+		+	++	+++		+
Estuary	+++				++	+++	
Aquifer	+			+		+	+++

2.2.4 Type of service

35 The type and level of service that can be provided is balanced between the technical feasibility of forecasting flood hazards and the economic justification for protecting vulnerable populations

and infrastructure. The different types of services, from the basic level to levels of highest quality, are summarized as follows:

i **Threshold-based flood alert:** This is not quantitative forecasting but rather a qualitative estimation of the increase in river flows or levels. Extrapolations are made at time intervals to revise the projection of potential or actual flood conditions.

ii **Flood forecasting:** This is a more definitive service based on simulation tools and modelling. Simulation can involve using simple methods such as statistical curves, level-to-level correlations or time-of-travel relationships. These methods allow a quantified and time-based prediction of water level, enabling flood warnings with an acceptable degree of confidence and reliability.

iii **Vigilance mapping:** This is a development of the site-specific warning approach described in (ii). Flood warning services in a number of countries now produce map-based visualizations as an Internet service (for example the "vigilance map" in France). The levels of risk derived from observations or from models are characterized by a colour code (in the French example, green, yellow, orange, red) indicating the severity of the expected flood.

iv **Inundation forecasting:** This is the most sophisticated service and requires combining a hydrological or hydrodynamic level-and-flow model with digital representations of the flood plain land surface. The level of detail and accuracy of the terrain model depends on the nature of the area at risk. Such models can predict flooding at very precise locations, for example housing areas or critical infrastructure such as power stations and road or rail bridges. Developing this approach requires a thorough knowledge about inundations associated with earlier severe events.

2.2.5 Forecast Lead Time

36 The basic criterion for assessing lead time requirements is the minimum period of advance warning necessary for preparatory action to be taken effectively. This will depend on the needs of the target community or area. On large rivers with a major potential impact, the lead time for evacuating populations at risk may be on the order of days. The concept of lead time has to be flexible and the minimum time may be entirely dependent on the catchment structure and on forecasting and warning system facilities.

2.3 Data Requirements

37 Flood forecasting and warning requires different sets of technical data that comprise:

i Hydrological data: river level and flow in general and specifically for forecast points and at-risk sites;

ii Meteorological data: rainfall data, weather forecasts and rainfall event warnings;

iii Topographic data: physical geographic definition of factors that affect runoff and may be required for models; and

iv Structural and social data: location of the population, at-risk sites, reservoirs and flood protection, power and transport infrastructure.

2.4 Infrastructure and Human Resources

38 It is now recognized that the importance of flood forecasting and warning in managing flood risk and impacts requires a full-time structured organizational approach. The facilities of flood forecasting and warning services include physical infrastructure:

- i A central operational base;
- ii A network of dedicated observation stations;
- iii Communication (telemetry) to outstations;
- iv Accommodation for operating staff;
- v Locations for monitoring and modelling facilities;
- vi Facilities for disseminating forecasts and warnings.

39 Similarly, adequate and qualified staffing of flood forecasting and warning units is imperative, given the level of present-day risks and the impacts on populations, property and infrastructure. There is no fixed optimum pattern to follow, but the following capacities must be available:

- i Hydrological forecasters and modellers;
- ii Meteorological forecasters (in the case of the meteorological and water management services being separated);
- iii IT and operational technical communications specialists;
- iv Communication specialists conversant with the media, the public and the government;
- v Management and administrative personnel;
- vi Researchers for continued research and development.

2.5 Establishing the Concept of Operations

40 Operations are defined as the interaction between data, forecast technology and users. This definition sets out how the operational forecast service will function to meet user requirements. There are many ways to configure an operational forecast service reflected in the variety of country forecast operational structures. There are, however, a number of critical factors ensure credible delivery of service to meet the needs of diverse user communities.

41 Once the operational concept has been articulated, it is included in the operations manual that defines the day-to-day operating environment ("background" or "standby") as well as delineating forecast service operations during flooding conditions. The mandate for service provision is usually defined in a statutory manner. There are likely to be many users having different forecast and information needs. Examples of users include emergency services, civil defence or contingency managers, the media, agriculture, water resource and flood control, industry, hydropower and municipal water supply organizations and transportation infrastructure.

42 The operational policy and role of the forecast service under both full operational and standby conditions must be considered carefully. Under the operating conditions, that is, during active

flood warning operations, the role is to collect data; perform quality control on information; receive and analyse meteorological forecasts; run the forecasting systems; analyse present and future hydrologic conditions; and produce the forecast products for distribution to users. Under severe event conditions, data flow volume and staffing resources may need to be increased since more products must be delivered to more users with short deadlines.

43 In standby conditions, staff members have to maintain and improve the functions of the centre. This includes activities like updating essential data such as rating curves and probability estimates, evaluating operational performance such as forecast lead times and timely delivery, equipment maintenance, calibrating and refining models, analysing opportunities to improve future forecasts and producing post-event reports.

3 FLOOD FORECASTING MODELS AND MONITORING NETWORKS

3.1 Introduction

44 The expectation that flood forecasts accurately predict magnitude and timing has grown with the recognition of the importance of flood warning to flood management. *"The heart of any flow forecasting system is a hydrological model"* (Serban and Askew, 1991). Catchment modelling is just one of the crucial elements on which the effectiveness and efficiency of an integrated flood forecasting and warning system (FFWS) depends. The required steps for creating a suitable flood forecasting model are illustrated in **Figure 3**. A hydrological forecast is an estimate of the future state of some hydrological phenomenon such as flow rate, cumulative volume, stage level, area of inundation or mean flow velocity at a particular geographical location or channel section.

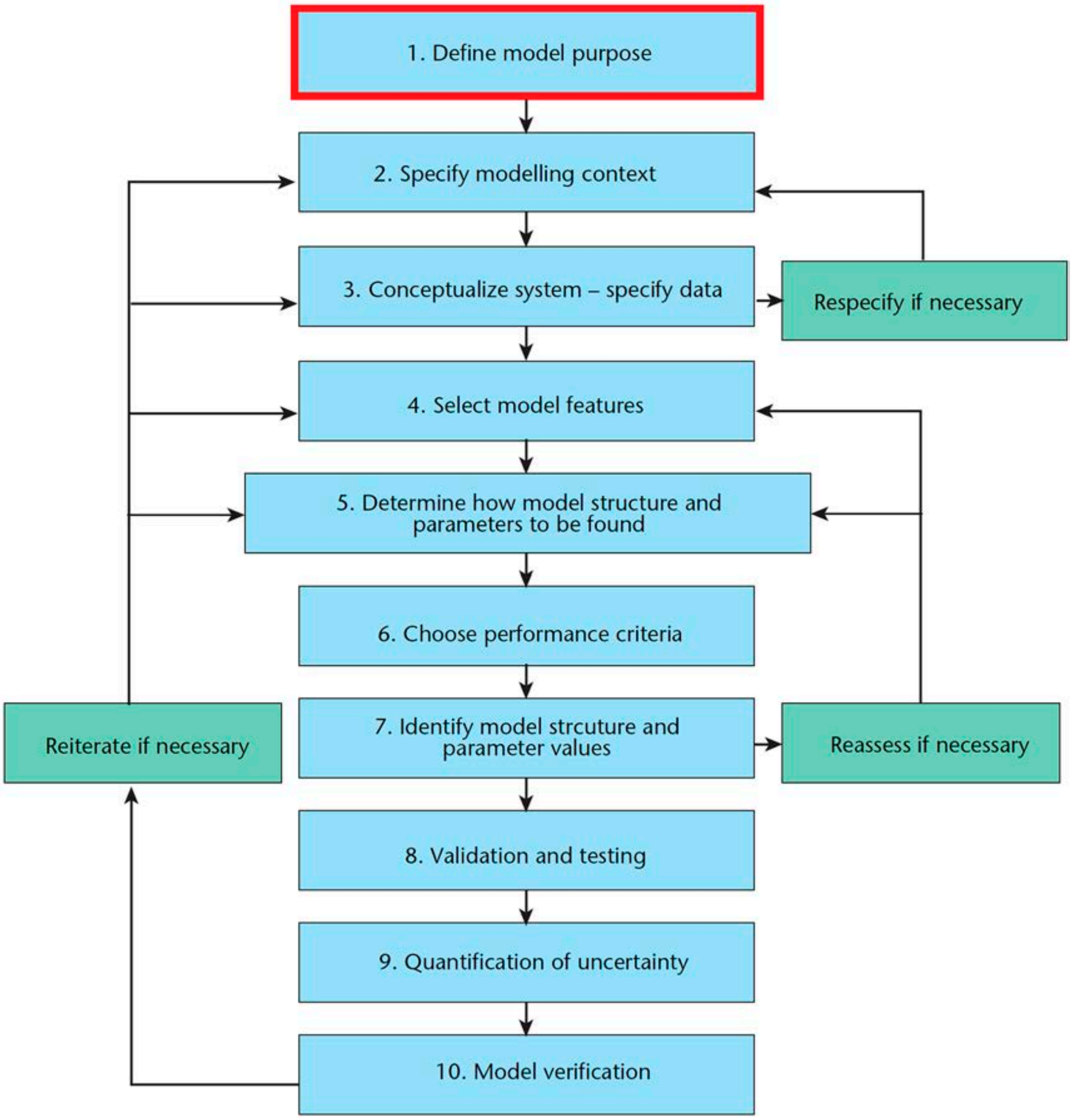

Figure 3 — Process for developing a flood forecasting model

45 Forecast lead time is the period from the time of origin of the forecast to the future point in time to which the forecast applies. Definitions of categories of lead time are subjective, depending on the size of the catchment within a particular region or country.

3.2 Flood Forecasting Model and its Selection

46 Floods can be forecast using complete rainfall-runoff models or using routing models. The literature on flood forecasting is full of examples of both types of models being used successfully for flood warning purposes. Usually, routing methods-based flood forecasting models are simpler and less data-intensive. Broad classifications of various flood forecasting model types falling under rainfall runoff models along with methods relying only on the routing to downstream of an observed wave are as follows:

3.2.1 Precipitation-driven Catchment Models

47 Rainfall–runoff models are designed to produce the required flood forecasts from meteorological and other data, so the choice of model, as well as the estimation of Quantitative Precipitation Forecasts (QPFs) over the forecast lead times, is crucial. Rainfall-runoff models can be classified broadly as black box models (e.g., stage regression), lumped parameter models (e.g., Sacramento), and spatially distributed models (e.g., TOPMODEL). However, the 'one size fits all' approach to catchment modelling and forecasting does not work.

48 Best management practice in FFWSs is evolving towards using more physically-based distributed models or at least an integrated suite of simplified models running simultaneously. To be useful, selected forecasting models must satisfy certain objectives depending on the requirements of the stakeholders and the end users of the forecasts.

49 Simulation of runoff from precipitation (rainfall-runoff models), produces the required flood forecasts from meteorological and other data. The models require good quantitative precipitation estimates (measurements from rain gauges) or forecasts QPFs, along with information about the characteristics of the catchment in terms of location (arid, humid etc.) and size. The major components are:

- i Precipitation monitoring and forecasting (includes snow);
- ii Event modelling;
- iii Continuous simulation;
- iv Real-time updating during events;
- v Parameter estimation and calibration.

3.2.2 Routing Models

50 Flood forecasting methods that are based solely on routing of an upstream flow to a downstream forecast point can be classified as hydrologic or hydraulic methods. Flood routing is the process of modelling the change of shape of the hydrograph from upstream to downstream, i.e. attenuation. The change of shape can be influenced by reservoirs, channel characteristics, joining of tributaries and flood-plain storage. Routing a flood through the concentrated storage of a reservoir or the distributed storage of a reach of an open channel is a mathematical procedure for estimating the changes in magnitude, speed and shape of an inflow flood hydrograph at one or more downstream points along a channel as the flood wave moves downstream. The outflow hydrograph at the downstream section is characterized by a proportionally lower peak, a longer time base and a time lag between the peaks of the inflow and the outflow hydrographs, i.e. attenuation. Routing techniques are broadly classified as either a) hydrological routing, or b) hydraulic routing.

51 The routing techniques are broadly classified as either hydrological or hydraulics routing as shown in **Figure 4** below.

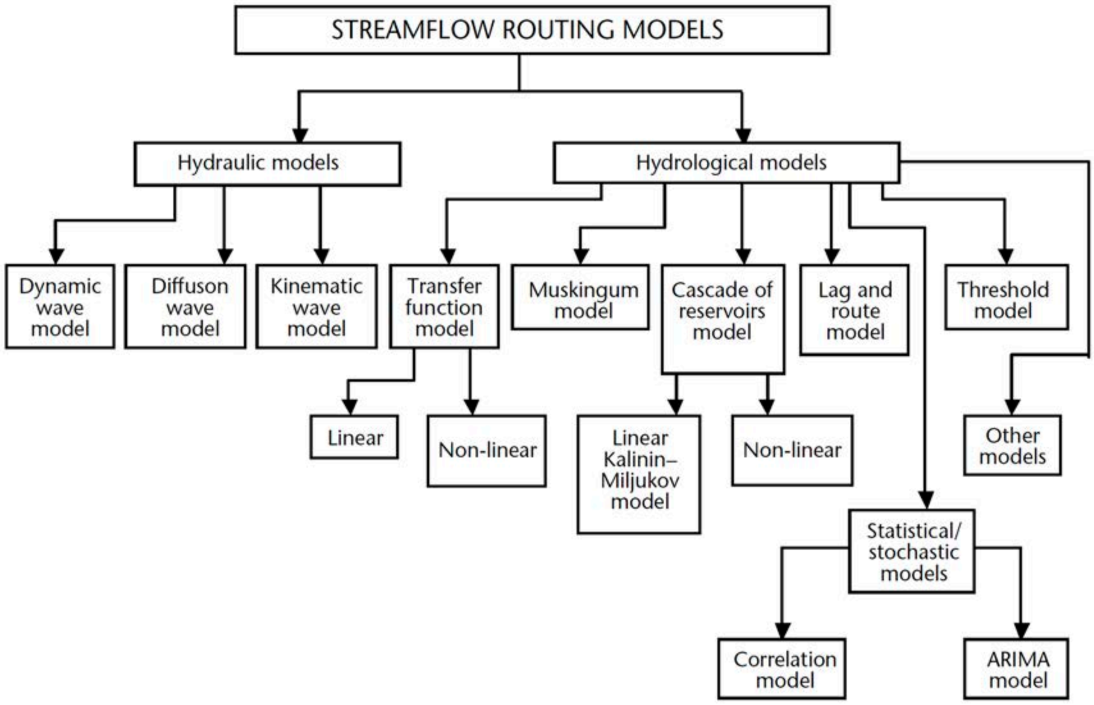

Figure 4 — Classification of streamflow routing models

3.2.3 Combined Catchment and Routing Models

52 In practice, most flood forecasting and warning operations use a complex suite of combined models:

- i Catchment models are used to simulate the response of the catchment that produces runoff at a point which, depending on the type of model and scale used, may be the outlet of a Hydrological Response Unit (HRU), i.e. a parcel of the landscape or distributed model grid element, a sub-catchment or the entire catchment;
- ii This runoff is then routed appropriately using different procedures, depending on the type of model and scale of application, to obtain the simulated flow at the point of interest in the catchment.

3.2.4 Special Case Models

53 There are many models that have been developed for special cases of flood forecasting and flooding scenarios. Some of the models used are (i) storm surge models, (ii) flash floods, (iii) urban flooding and (iv) reservoir flood control. These models have different applications and limitations and are used exclusively for particular cases.

3.2.5 Model Availability

54 It is becoming increasingly rare for model developments to take place "in-house", due to the complexity of modelling and systems management required. More commonly, development is contracted out to a specialist consultancy. Another source of well-established models is the World Wide Web; free downloads, or downloads at a price, are possible in many cases. However, these sources do not usually provide ongoing support, training or development.

55 In the UK there has been a move away from individual catchment management agencies developing their own models to a more integrated approach known as "an open architecture system". The core model structures are provided by a major specialist in flood modelling, but some existing systems (legacy systems) are incorporated. In order to increase the lead time for flood prediction, the system is coupled with state-of-the art NWP models from the UK Met Office. The use of standard, specific models is the norm in many countries, e.g. France, Germany, Italy, USA, Bangladesh, Korea and the Mekong River Commission.

3.3 Choosing the Appropriate Model for Flood Forecasting

56 The main factor affecting the choice of a method or of a model for flood forecasting is understanding and correctly defining the purposes for which the method or the model will be used. The availability of data strongly influences the selection of the type of modelling approach. Approaches range from simple statistical methods to extremely detailed physical-process models. With respect to real-time flood forecasting, the following additional factors have to be considered when selecting a model:

- i Forecasting lead time versus time of concentration/travel time in the river reach;
- ii Robustness in dealing with instabilities or large forecasting errors even if slightly less accurate approaches are adopted;
- iii Computational time to ensure that the forecast is available in time for the flood managers and dependent responders to guarantee effective decisions. In practice this requirement discourages using sophisticated and accurate approaches that are nevertheless time consuming.

57 There are a number of specific issues that may limit the use of one type of modelling approach compared to other ones, and these are as follows:

3.3.1 Choosing the Appropriate Model

58 There is no specific type of model that can be chosen as the most appropriate for flood forecasting. Each category of models has its own characteristics. As a general rule of thumb, the forecasting model must help reduce the forecasting uncertainty. There are a number of specific issues that may limit the use of one type of modelling approach compared to another one, and these are:

59 **Data-driven models:** these are generally simple and easy to calibrate, but many end-users fear that the models may be unreliable beyond the range of the historical data on which they are based. They should be used where: (a) the predictand, namely the quantity of interest to be forecast, is at a gauged river section (extension of their use to ungauged cross sections is practically impossible); (b) relatively long data time series are available that encompass most of the range of variability over time of the predictand; (c) the required forecasting span is relatively short compared with the concentration time of the catchment to the cross section of interest.

60 **Conceptual (hydrological) models:** Conceptual models are the most widely used for flood forecasting because they are more easily understood by flood managers in that they try to describe rationally the different components of the hydrological cycle. Continuous time

conceptual models should be used where: (a) the predictand is at a gauged river section; (b) relatively long data time series are available that encompass most of the variability over time of the predict and; (c) the required forecasting span is of the same order of magnitude as the concentration time (or the travel time) to the cross section of interest.

61 **Physical-process models:** In physical-process models, the different parts of the hydrological cycle are more specifically represented by the mathematics of the physical process, for example fluid flow in rivers and through porous media in aquifers. In particular, spatially distributed process models should be used when: (a) sufficient geo-morphological and hydro-morphological data are available; (b) there is a particular requirement to extrapolate the forecasts to ungauged locations; (c) the model computational time required is sufficiently small to allow for timely forecasts; (d) the rainfall input is available in spatially distributed form (for instance as pixels from radar output); and (e) the spatially distributed rainfall input shows marked variability over different parts of the catchment.

62 The Hydrological Operational Multipurpose System **(HOMS)** has been established by the World Meteorological Organization for transferring technology in hydrology and water resources. This technology usually takes the form of descriptions of hydrological instruments, technical manuals or computer programs, material made available for inclusion in HOMS by the Hydrological Services of member countries of WMO based on techniques that they themselves use in their normal operations. This is an important aspect of the HOMS philosophy because it ensures that the technology transferred is not only ready for use but also works reliably[2].

3.3.2 Understanding Flood Hydrology

63 It is essential to understand the causes of flooding in any given catchment or river basin while developing flood forecasting models. The size, shape and topographical structure of the catchment control the basic response to the key driver of flooding, which is the input of precipitation. Land use, geology, soils and vegetation affect the speed of response of the catchment to rainfall, and the losses to soil and deeper recharge are also major features of flood response.

64 The nature of the precipitation causing flooding needs to be fully understood in the context both of events and of seasonal climatology. Different types of precipitation cause varying responses in a given catchment, and the relative importance of the impact of different types of events needs to be evaluated in order to define the most appropriate approach to developing flood warning. Under these conditions, modern techniques of remote-sensing can prove more useful than conventional instrumentation. It may be possible to use satellite or radar-based monitoring to observe rainfall. River conditions need to be observed at suitable places for locations at risk, but it is imperative that these observations provide adequate lead time, since the high speed of flooding is also a common feature in arid and semi-arid regions.

65 The focus of flood risk and the required responses for flood forecasting and warning have to be determined from detailed studies. Lately this has been characterized by the "Source-Pathway-Receptor" approach, as illustrated in **Figure 5**. Understanding of flood hydrology must extend from the catchment and river system to the "targets". These can range from scattered,

2 HOMS can be accessed through the WMO website: www.wmo.int/pages/prog/hwrp/homs/homs_en.html.

poorly connected, rural settlements in flood plains subject to major inundations, to major urban centres with a concentration of high-value, sometimes critical infrastructure such as hospitals. Both have specific time-critical requirements for receiving the necessary warning information concerning the location and potential extent of flooding. Different targets may need varying approaches to providing the information required for an effective response. For example, rural flood plain populations will need time to move livestock and property to higher areas or to purpose-built flood refuges. Urban areas will need time to organize road closures and diversions, erect temporary flood barriers as well as for possible evacuation.

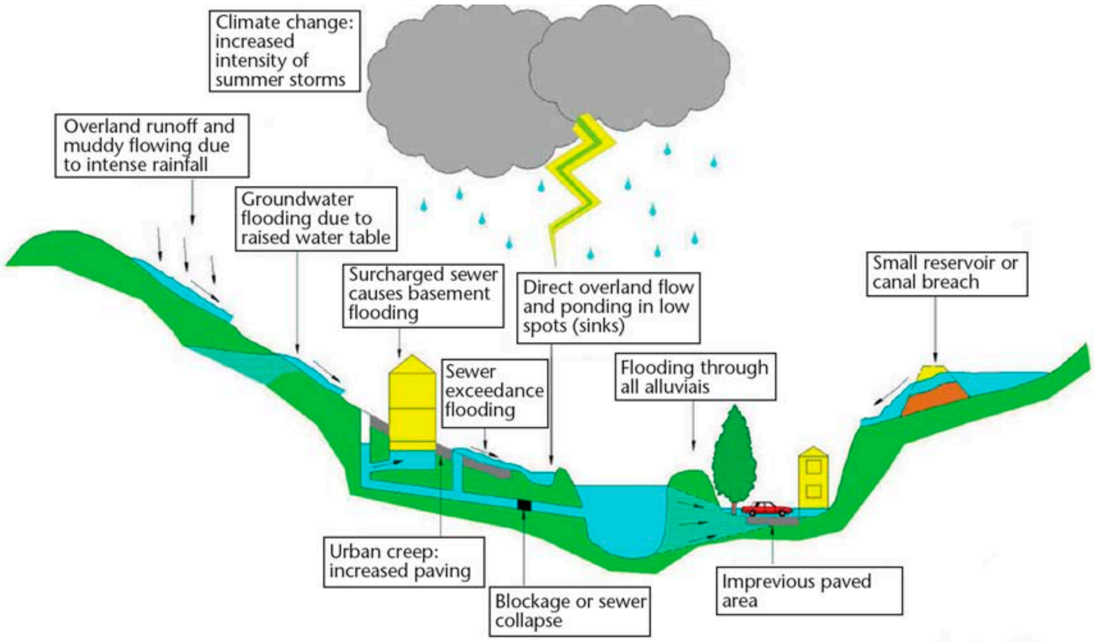

Figure 5 — The source-pathway-receptor approach (Hankin et al., 2008)

66 A feature of understanding flood hydrology that is often neglected is identifying how floods decline after the peak is passed. This is important to know in order to determine when access is available, first perhaps by emergency vehicles and by the plant needed to initiate immediate repair works, and later to allow occupants to return. Most flood warning systems include an "all-clear" or "out-of-danger" category concerning river levels. However, many lower areas of major catchments, especially deltas, can remain flooded much longer after higher river levels have declined. Likewise, catchments with strong groundwater contribution can remain flooded from groundwater sources for extended periods of time.

3.3.3 Requirements for Analytical Flood Studies

67 Flood analysis is required essentially to identify the characteristics of the relevant flood hydrograph for the catchment in question. In effect, the hydrograph provides the complete integrated picture of rainfall and catchment characteristics. When the hydrograph is seen in relation to channel capacity and flood plain topography, the two-dimensional nature of the level or flow quantity against time can be considered in a third, spatial dimension. The necessary information for analytical studies is obtained from:

i daily recording rain gauges;

- ii water level recorders with rated sections or measuring structures to provide river discharge measurements;
- iii climatological data, particularly to provide estimation of evaporation losses and water balance;
- iv general topographical and land-use mapping to define catchment characteristics;
- v detailed topographic survey of the river and adjacent flood plain (the flood corridor or functional flood plain); and
- vi identifying areas at risk, which may require a more detailed topographical survey and accurate flow measurement.

68 These data provide the building blocks for model studies, calibration of models and identification of the flood warning system requirements. Although similar to general flood studies, the focus on an operational forecasting and warning system requires accurate knowledge of the timing of flood response and the speed of flood movement. It is therefore essential to have access to sets of information (at the very least rainfall and flow) from various contributing portions of the catchment, particularly data from its upper reaches. The essential requirements are as follows:

- i Measurement of rainfall and runoff from main upland portions of the catchment (watershed), to define early flood generation;
- ii Measurement of rainfall, runoff and timing close to the major confluence points within the river system to identify the time of travel and the relative significance of different catchment contributions;
- iii Measurement of river levels, flows and flood plain characteristics upstream of high-risk areas;
- iv Identification of drainage congestion problems in lowland areas, needing accurate water level measurement and timing; and
- v Local rainfall data in areas of drainage congestion and urban areas to identify pluvial flood risk.

3.3.4 Model Calibration and Data Requirements

69 Ideally, the objective of calibration is to remove all possible bias and eliminate all possible noise included in the model. In reality, because of the constraint of input data quantity and quality, and of simplistic assumptions that may be inherent in the model, care should be taken to achieve the proper balance between the calibration objectives and goodness-of-fit statistics. Generally there are three main objectives when calibrating conceptual hydrologic models to an entire river basin for river forecasting applications, namely:

- i A good reproduction of the observed hydrograph at each individual key forecast point on the river system should be produced;
- ii The parameters of the models should function as they are intended;
- iii There should be a realistic variation in parameter values from one area to another within the river basin (headwater, mainstream or tributary) and with areas just across the divide in adjacent river basins.

70 In general this means that the chosen model parameters need to be adjusted in order to make the model predicted values resemble the observed values. It is important to recognize that model parameters may not fully incorporate a physical meaning but are mostly uncertain quantities that reflect all the error sources. There are two basic methods used for calibrating

hydrologic models: i) trial and error calibration and ii) automated (parameter) optimization calibration.

71 When calibrating any hydrologic models there are five steps that should be followed:

- i Gather information and data;
- ii Assess spatial variability of hydrologic factors;
- iii Analyze historical data and prepare it for use in hydrological models;
- iv Select flow-points and period of record for calibration;
- v Implement calibration results for operational use.

72 **Data requirement:** In terms of data types, basic climatological information, spatial (geographical) and physical information on the nature of the river system, vegetation cover, land-use, soil classification and geology are essential. Commonly, meteorological and hydrological services consider the data over 30 years as the standard period.

73 **Other requirements:** Some of the most important requirements are knowledge, experience, teamwork, leadership, computerized tools, along with following proven procedures and strategies. Innovation may be required during the calibration process. Using tested procedures and strategies for model development will make model procedures efficient and give consistent, good quality results. Thus a number of standard, internationally-available models are used as the basis for most flood forecasting systems.

3.3.5 Model Verification / Validation

74 A fundamental rule of model verification is to verify according to data not used in calibration. The validation period used for verification should be long enough to incorporate several observed flood events, so it may need to cover two or more years. A number of statistical methods are available for evaluating the success of verification. Common analysis methods are listed in the WMO Manual on Flood Forecasting and Warning. Visual comparison of simulated and observed hydrographs provides a qualitative evaluation of simulation skills. In flood forecasting applications, comparisons should focus on alarm levels, forecast lead time etc. Accurate representation of flood volume is critically important, as it demonstrates how effective the model is in relating rainfall and runoff responses. The shape characteristics of the modelled and observed floods can be statistically tested according to three parameters:

- i Peak percentage difference between observed and simulated floods;
- ii Phase-difference of the peak flow (hours);
- iii Volumetric difference.

75 **Forecast verification criteria:** These are an established feature of meteorological and hydrological best practice, through which the forecast (model-based) output is compared retrospectively to observations. Forecast verification is carried out periodically, for instance at the end of a flood season. A number of measures may be employed: Probability of Detection **(PoD)**, Hit Rate **(HR)**, False Alarm Rate **(FAR)**, The Brier skill score, Continuous Measures, such as Bias (mean error), root mean square error **(RMS)** and mean absolute error **(MAE)**. These are all relative values, i.e. there is no "right" or "wrong" score. A selection of criteria, together

with their rationale, is summarized in a document, publicly available at the Australian Bureau of Meteorology website[3].

3.3.6 Data Assimilation

76 In real-time flood forecasting, a large number of observations have to be collected in real time. These observations cover a range of variables to be used as model inputs and include additional information to provide model adjustment. The scope of data assimilation is to incorporate this information into the model state variables or into the model parameters in order to improve forecasting performance. This is a complex procedure of mathematical analysis, using the Kalman Filter and its derivations in order to quantify dynamic changes in state and model variables over time steps within the updating process. The WMO Flood Forecasting and Warning Manual should be consulted for a fuller explanation and references.

3.3.7 Coupling Meteorological Forecasts to Hydrologic Models

77 The ultimate goal of flood forecasting is to provide accurate forecasts of hydrological conditions from a meteorological forecast situation. Deterministic and probabilistic or Ensemble Quantitative Precipitation Forecasts **(EQPF)** and other forecasted meteorological parameters can be applied as input to hydrological models. Meteorological forecasts are becoming increasingly definitive and useful as input to hydrological modelling. Thus National Hydrologic Services **(NHSs)** and National Meteorological Services **(NMSs)** need to coordinate and collaborate closely to maximize the quality and value of meteorological products and services for the water resources user community.

78 Coupling meteorological forecasts and hydrological models must be considered as a separate approach, different from using outputs from meteorological models as discrete inputs into hydrological forecast models. Though the hourly time-step used by NWP models satisfies most temporal requirements for flood forecasting, their spatial scale severely limits application. The opportunities for model coupling are therefore greatest for larger catchments.

79 **Predictive Uncertainty in Operation:** Hydrological and meteorological forecasts have inherent errors and uncertainties, and these may be significant consequences in flood management operations. Nonetheless, emergency managers are required to make decisions under the stress of uncertainty about the evolution of future events. One of the issues in the debate among hydrologists is how to use predictive uncertainty beneficially in operations. Although a flood forecast has benefits, there is a problem in communicating uncertainty to the end-users and decision makers, such as water managers, emergency managers, etc.

3.4 Operational Hydro-Meteorological Networks

80 Many factors need to be considered in designing an operational network to support a flood forecasting and warning operation. Essentially, the network is based on a combination of rainfall and river level (and flow) monitoring points reporting in real time, or near real time, to a

3 WWRP/WGNE Joint Working Group on Forecast Verification Research: Issues, Methods and FAQ. www.cawcr.gov.au/projects/verification/

central operation and control system. Networks must be highly reliable and resilient. They are largely built upon automatic data monitoring, processing and retrieval, and have to be operated as a single entity. The data network must deliver information about areas where the high risk of flooding combines with the high impact of floods. There must be a sufficient number of stations reporting the details to allow observation of the development of the flood, providing sufficient time for forecasting models to produce outputs so that timely warnings can be issued and necessary decisions made.

81 Networks used for flood forecasting and warning systems are most frequently developed from existing hydro-meteorological networks. This influences the structure of the network while limiting the need to introduce entirely new sites. The use of existing networks is beneficial because along with equipment and site infrastructure, the locations used will possess an established database that will provide a good information foundation for model development. The value of existing networks must be assessed according to their geographical suitability and their representativeness for flood forecasting purposes. Because existing networks may have been developed by separate operational entities such as water resources organizations and meteorological ones, there may also be ownership and management issues to consider.

3.4.1 Types of Existing Monitoring Networks

82 **Meteorological networks:** These observation networks, operated by NMSs, have generally evolved historically because of two main needs: i) for synoptic observations to record current weather conditions and develop weather forecasts, and ii) for observations to build up information for general and specific climatology.

83 **Rain gauge networks:** Rainfall has been observed over many years in most countries, principally on a daily basis, but only a small proportion of observations record rainfall on a continuous basis. Development of rain gauge networks has been piecemeal and has been much influenced by differing purposes, so the size and composition of networks change over time. Rain gauges may originally have been set up by: i) local administrative centres, ii) water and sewage treatment works, iii) reservoirs, iv) agricultural and forestry establishments, v) irrigation services, vi) research units, and vii) schools and colleges.

84 **River gauging (hydrometric) networks:** River gauging networks have also been developed by a number of organizations before the operation of these networks was taken over by a national authority. Thus sites may be specific to water management structures, and are likely to be found predominantly in lowland areas. Few suitable sites exist, therefore, that can provide early warning of flood development. The bias in favour of water management tends to focus on accurate measurement of low flows, and measurement structures are not designed to measure high flows or out-of-bank flows, both of which measurements are vital for flood routing and inundation modelling. If existing river gauging sites are selected as part of a flood forecasting and warning system, their design will require significant modification.

85 As with rain gauges, the original purpose of most flow gauges required that their data was only sampled and analysed at intervals. Thus water levels, whether manually recorded at set times, e.g. daily, or continuously recorded in some way (chart, logger), rarely provided data in real time. Flow, in particular, was calculated retrospectively in batches.

3.5 Design Requirements for Hydro-meteorological Observation Networks

86 The following are the basic structures of the observation system needed to provide the model with the required data as well as with knowledge of the salient issues for network design:

3.5.1 Identification of Risk Areas

87 Flood forecasting and warning must be focused on the communities and infrastructure within a river basin or other management area (city, district, region etc.). Some early attempts at flood forecasting and warning focused too much on hydrology and not enough on the at-risk areas. This occurred because of the origin of these systems in existing hydrometric networks and because the information was primarily for internal use by catchment managers. A wide range of sites in a catchment may be at risk from flooding and need to be prioritized in terms of the level of risk and the likely magnitude of impacts. Levels of risk can be categorized according to probability related to particular trigger levels, and the level of impacts can be usually be classified in terms of economic costs and disruption.

88 Categorizing the impact zone with type of land use may vary from basin to basin or according to the relative importance of, say, agriculture and industry within the national or regional context. Certain general categories serve to illustrate the concept. A matrix analysis can be a useful approach because thereby the risk and impacts over different categories can be related to recipient benefits from flood forecasts and warnings. Details of flood risk land-zone classification are given in **Annex II**.

Table 3 — Flood impact zones

Flood risk	Flood Impact Zone: Undeveloped area (low)	Agricultural land (medium)	Low density urban (high)	Urban centres & key infrastructure (very high)
High	High/low	High/medium	High/high	High/very high
Medium	Medium/low	Medium/medium	Medium/high	Medium/very high
Low	Low/low	Low/medium	Low/high	Low/very high

The colour codes, green-yellow-orange-red, are indicative of the importance/benefit of flood forecasting and warning

3.5.2 Components of flood risk

89 Fixed risk, derived from various catchment variables such as shape, river channel steepness, channel hydraulics and obstructions in urban areas, along with at-risk housing and infrastructure

90 Antecedent risk, dependent primarily on the monitoring of catchment wetness, reservoir states and snow cover

91 Event risk, which contains most of the variables included as inputs in models or decision support frameworks (DSF), e.g. rainfall quantity, distribution and intensity, changing river state, storm movement, QPFs.

92 Mapping of fixed risk is an effective means of defining the most critical areas, and thus those areas where the greatest effort must be made to provide an adequate network.

3.5.3 Selection of appropriate lead times

93 The lead time provided by a flood warning has to be sufficiently long to allow response action to take place. Lead time has to include delivering data from the observation system, and model forecast runs have to be fast enough to have the information available in time for forecasts to be issued.

94 Usually a flood can be predicted with high accuracy only in the later stages of its development, when more information such as observed rainfall becomes available. Therefore, in order for sufficient warning time to be provided it is often necessary to accept a prediction that is less accurate. There is therefore a trade-off between prediction accuracy and warning time. **Figure 6** illustrates an example of the trade-off between the warning time that can be provided and the level of accuracy.

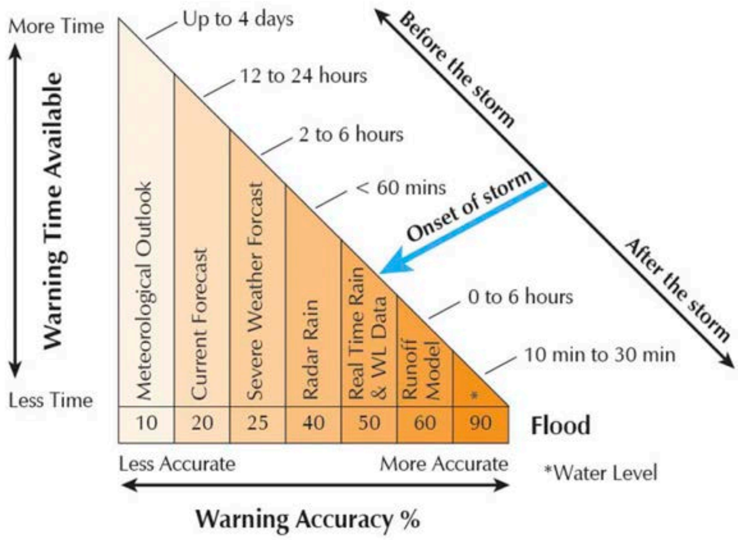

Figure 6 — The trade-off between warning time and flood forecast accuracy for flash flood situations (Wright, 2001)

95 Catchments can be categorized by time to peak (Tp), e.g., zero-to-three hours, three-to-nine hours and greater than nine hours. Many flood warning agencies provide forecasts and related warnings for a period 48 hours ahead (T+48). In small catchments like in the UK, lead time of two hours is considered to be a minimum for rapid response catchments. In Bangladesh, with slow-responding rivers, the forecast horizon is 72 hours (T+72). In these cases the river situation is usually reported at specific intervals, which could be steps of three or six hours.

3.5.4 Background Catchment Monitoring and Preparedness

96 The monitoring of background or antecedent conditions is essential for initiating model runs, especially where monitoring intervals and operator numbers have to be raised from routine or standby to fully active status. It can also be an integral part of model updating whereby the relevant variable and algorithms are revised at fixed periods. More complex forms of

catchment wetness, such as soil moisture deficit (SMD) or runoff potential, use both rainfall and evaporation, and therefore depend on both rainfall and climate data being monitored and a suitable method of calculation of actual evapo-transpiration to be made.

3.5.5 Instrumentation and Monitoring

97 Speedy and reliable delivery of data from the field to the operations centre is of paramount importance in a flood forecasting and warning system. Instrumentation required uses electronic sensors and automatic transmission. The basic types of instruments used are: a) tipping buckets rain gauge, b) water level recorders, c) ultra-sonic flow measurement devices, d) climate stations (automatic weather stations - AWS). Full details of instruments and discussions about their location and siting can be found in the referenced WMO guides (WMO, 1983, 2007, 2008).

98 Most modern instruments are modular, relying primarily on electronic circuitry and micro. processors. There is little adjustment or repair needing to be done by technical staff within the operating authority. Technical staff check instrument operation and power supplies, along with doing occasional calibration checks and verifying structural integrity. Sensor, processor and transmitter housings and mountings need to be of high specification, especially where extreme weather conditions occur.

3.5.6 Suitability of Data Structures

99 The format of data produced is an important part of instrument specification. This assures that data are produced in the correct formats for input to data processing routines and models. The most important transfers are: i) signals from the sensor to a digital data format; ii) transmission of digital data in a communications format; and iii) conversion of transmission data in digital format for input to processing and models

100 Information is also provided in visual display form, e.g. radar and satellite imagery and numerical weather prediction. These data are processed into final form using pixel arrays, which means that they lend themselves to digital conversion. However, the volume of data involved is very large, and in only a few cases have systems been developed to convert visual data to a directly useable input format, e.g. HYRAD (UK), NEXRAD (USA). Use of pixel-based data also means that forecast models have to accommodate grid-based data rather than data inputs at specific points.

3.5.7 Software Operating Systems

101 A number of separate systems contribute to the overall structure of flood forecasting and warning operations. It is essential for these separate systems to link effectively, with a high degree of automation and only a minimum amount of human intervention. Most of the major suppliers of flood forecasting and warning software use an "open architecture system". Typically, these systems provide a dedicated user interface for hydrological and hydraulic models and on-line meteorological and hydrological data collection. In open architecture systems, the "shell" incorporates a wide range of general data handling utilities while providing an open interface with core of forecasting models. Typically these will include:

– a hydrological cycle (rainfall-runoff) model;

– a river channel hydraulic model;
– a river channel and floodplain model;
– an automatic alert generating model.

102 Sophisticated operating systems provide a wide range of display modules and graphics, which form the Graphic User Interface (GUI). All these operating systems contain sub-systems for graphical, tabular and map-based summaries. The structure can be customized to the specific requirements of an individual flood-forecasting agency. A typical example of an "open architecture" or "shell" system is shown in **Figure 7**.

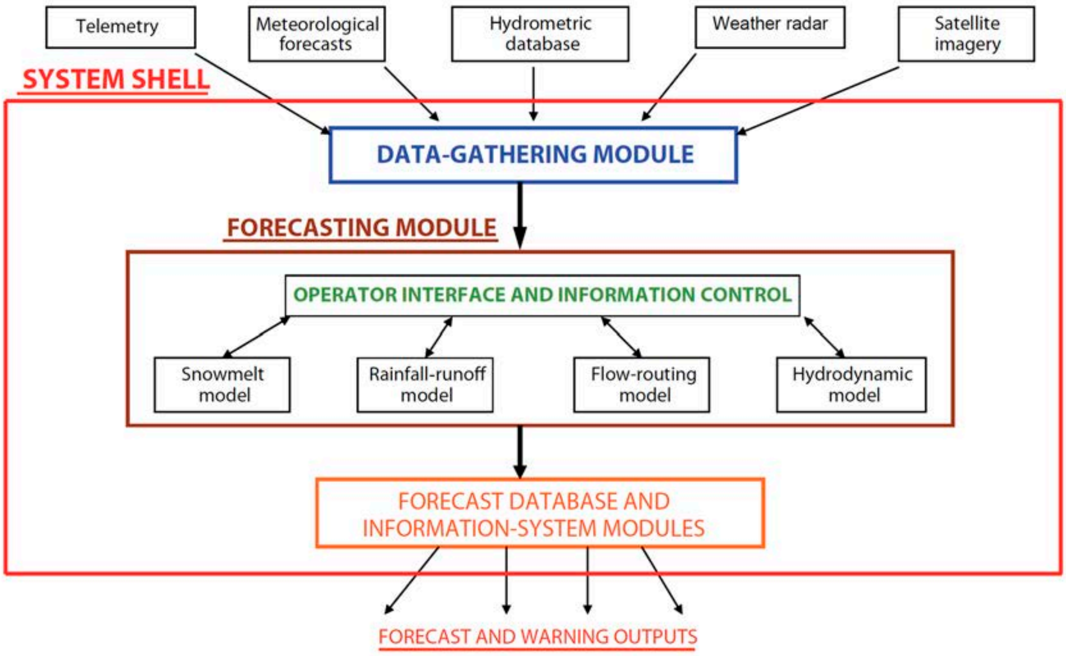

Figure 7 — The open architecture system structure (after Wallingford Software)

3.5.8 Operation and Maintenance of Hydrological Networks

103 Highly critical aspects for flood forecasting and warning system operations are that the system:

i covers a wide range of equipment and mobility;
ii maintains communications with third parties or service providers; and
iii maintains long-term financial arrangements for recurring expenditures.

3.6 Real-time Data Transmission and Management

104 To operate in real-time with data provided from current or very recent observations requires hydrometric data transmission systems (HDTS) that transmit data measured at remote telemetry stations to a receiving centre for further processing and operations.

3.6.1 Basic Requirements for Data Transmission

105 The HDTS should be designed with a full understanding of the necessity and importance of the flood forecasting and warning service, taking into consideration the following: (a) functionality; (b) geographical and physical constraints; (c) time structures for data and outputs; (d) installation conditions; (e) reliability and maintenance; (f) operator and public safety; and (g) economy.

106 The HDTS should be designed for optimal economic performance in terms of required functions and reliability relative to both capital and recurring costs. The economy of the system should be evaluated over the entire time span during which it is intended to function. The requirements for data observation and measurement should be based on operational purposes. The usual range of data items is as follows:

- i Data type and number of measuring points;
- ii Range of measurement, effective digits, measuring accuracy and resolution;
- iii Timing of measurement;
- iv Input interfaces;
- v Threshold values for detecting alarms;
- vi Outstation functionality reporting.

107 Data measurements may be transmitted without being processed, but it is more usual for data to be pre-processed at the sensors into a form that can be transmitted. Useful data manipulations include values totaled or averaged over a period, maximum and minimum values, etc. The bulk of data processing is normally carried out at the operational receiving centre in order to organize data in formats for model input.

3.6.2 Operational Storage and Memory Media

108 The HDTS needs functionality to store data and information in memory media on the system. Data storage in the HDTS is needed for:

- i buffering measured data until it can be transmitted to an information processing system. This can take place at individual remote stations or at the receiving centre;
- ii pre-processing of raw data into integrated time or area values, or an estimated value, e.g. evapo-transpiration from various climate variables;
- iii real-time generation of information by combining data at multiple time points;
- iv temporary storage of the real-time information necessary for decision-making.

109 Information that will be stored for a long time and used to provide standards or reference statistics (means, extremes, ranges) should be stored as a separate database and information-processing system from the HDTS, but accessible as part of the overall FF&W process.

3.6.3 Choice of Communication Channels

110 There are various means of transmitting data (telemetry), including wired lines, multiplex radio links (VHF, HF and UHF), public telecommunication lines, mobile telephone network

and satellite (VSAT) communication links. Each communication channel has its own specific technical features, advantages and disadvantages. Details are given in the WMO *Manual on Flood Forecasting and Warning*. The communication method selected has to be decided by taking into consideration:

i the communication facilities available in general within a country or region;

ii the amount of information to be transmitted;

iii the operating requirements in terms of delay time from field to centre, transmission speed and reliability of transmission; and

iv the economics and cost of the system.

111 Remote telemetry stations at hydrometric observation points are distributed over a wide geographical area. Telemetry stations cannot always be located at optimum hydrological sites, so depending on the communication medium, the system may need to provide relay or transfer stations, and these may be constraints. The networks of telemetry stations are determined by considering the distances from the receiving centre and the topography of the sites at the remote stations along with the availability of communication lines and radio links as well as radio propagation conditions (if radio links are chosen). Access roads are important factors for determining locations. Careful site and pathway survey are required to minimize interference and facilitate point-to-point communication given topographical conditions. Equipment components and radio link design should be appropriate in terms of frequency, transmission method, radio paths and terrain profiles.

3.6.4 Interrogation Methods and Frequency of Data Transfer

112 The HDTS will time-mark all data observations, but there will always be a delay time in delivering the data and their processing. Usually, sensors at remote telemetry stations measure hydrological variables continuously or at short intervals, e.g. 10 minutes for water levels. The receiving center decodes the received data and performs data verification and processing. An information processing system provided at this stage will convert the data into a suitable time series, e.g. 15 minute or hourly time step data for reports or date entry into models. The time characteristics and their allowable error range should be determined for the purposes of operations. There are a number of different methods for reporting data from remote sites. The reporting methods are a) cyclic polling, b) on-demand polling, c) batch polling and sequential report, d) continuous transmission, e) batch reporting, and f) event reporting.

3.6.5 Reliability

113 The environmental conditions at remote telemetry stations may be harsh, especially in tropical, desert and mountainous areas. Special care needs to be taken when using equipment outside temperate ranges or in harsher conditions than those for which instruments and electronics are designed for use. Therefore, both conditions inside the operational centre as well as outside atmospheric ambient conditions should be considered. Atmospheric conditions comprise temperature range and rate of change; relative humidity range; wind velocity; atmospheric salinity and dust. Environmental conditions inside equipment housing include available power supply conditions (including protection against surge currents due to lightning), potential for flood damage, access during flooding and seismic resistance.

114 Most equipment will have the manufacturers' recommendation for operating ranges, and these ranges should be carefully checked against expected field conditions. A highly-reliable power supply is essential for operating the HDTS, and requires careful consideration especially to remote telemetry stations. Systems of key importance, such as those at the central receiving and control unit and components requiring high-power capacity, should have guaranteed power backup. Time scales for backup operations range of from one week to one month but not longer. Specific points on two modes of power supplies are: (a) mains power supplies such as automatic voltage regulators (AVR), uninterruptible power supply systems (UPS), backup engine generators and lighting protection principally for operations centres and (b) non-mains (in-situ) power supplies such as photovoltaic (solar) power generation, wind turbine generation and batteries.

3.7 Data Pre-processing

115 Data used in a flood forecasting and warning system should be considered as a sub-set of larger databases covering hydrology, meteorology and climatology. The specific data and processing systems used should conform to the fundamental principles and guidance used in an established practice manual, the latest available Guide to Hydrological Practices (WMO-No. 168; 2009) and Guide to Climatological Practices (WMO-No. 100; 2011). Since flood forecasting and warning operations are conducted in real time, or near real time, many of the formal data processing routines for ensuring accuracy and consistency cannot be carried out. Therefore, steps have to be taken to ensure high quality and reliability from the source, and checks and balances must be built into the data processing system. This system is the primary source of reliable data for model inputs, forecasts and decision-making.

3.7.1 Quality control

116 Operational data management depends heavily on computerized data validation tools and techniques, but value checking by professionals should still be carried out, particularly where items are flagged by automatic controls. Hydrologists and meteorologists need to exercise informed judgment about whether to accept, reject or correct the data values so indicated. Validation techniques are devised to detect common errors that may occur, and normally programme output will be designed to show the reason for the data values being flagged. Data verification can be classified under two processes:

- i Error detection in data transmission, with methods often provided by the supplier as an integral part of the network system;
- ii Examination of the properties of incoming hydrometric data by comparing them with the known range of sensors, the upper and lower physical limits of data values and the limits of the rate of change of measured data.

117 Checking of plotted time-series of data visually by experienced personnel is a very quick and effective technique for detecting data anomalies. Rapid changes of a value or its trend are often pointers to erroneous or spurious data. Comparison with plots from adjacent stations is also a very simple and effective way of checking consistency. Validation methods fall into three main categories: (a) absolute checking, (b) relative checking; and (c) physico-statistical checking.

3.7.2 Missing Data In-filling

118 Any flood forecasting and warning system is highly dependent on the completeness and continuity of the data available. In-filling may be necessary to support functionality, but in-filling missing data must be done with extreme care. In-filling with a mean series value will be inappropriate for missing points in a flood event. Estimated data items should be flagged. Interpolated values for rainfall should only be estimated if the nature of the storm rainfall distribution is sufficiently regular. This may be effective for point rainfall measurements from rain gauges, but not easy to do for pixel-based estimates. A gap in a water-level record may be filled with a straight line or curve as applicable. Filling a gap in a data record with synthetic data derived by correlation is not recommended.

3.8 Development and Management of Data

119 The data management process focuses on data storage, access and dissemination.

3.8.1 Data Archiving and Permanence

120 Operational data received at a flood warning centre should also be saved in a reliable permanent archive. This provides a means for reviewing and analyzing past performance and for comparing historical events. It is important to decide which of the numerous datasets produced in a flood forecasting and warning operation should be stored – final summary data may not be adequate for future needs. The following points are common to data archiving and relevant to a flood forecasting and warning system:

- i Raw data files must be kept. These include records of the telemetered data, e.g. time of tip from TBRs;
- ii All processed datasets should be associated with descriptive metadata records detailing the origins of the dataset, e.g. instrument details, location information;
- iii Wholesale changes to parts of each series should be documented against the dataset, e.g. noting the application of a datum to a period of a stage record, or which rating curve was used;
- iv Changes made to individual data values, for instance interpolating missing data values or editing values separately, should be documented;
- v The resulting dataset should have a comprehensive catalogue of what has been edited and why.

3.8.2 Management of Data Storage and Access

121 When developing data storage systems, a number of important criteria must be considered, including: (a) security – this includes management of access and administrative rights for the various users; (b) ease of maintenance; (c) costs, consisting of initial outlay and recurrent costs including any software licenses required, maintenance and storage; (d) ease of query; (e) power of existing data query tools; (f) ease of development of additional query tools; (g) ability to include/link to other data sources or data display software, such as GIS; (h) suitability alongside existing IT infrastructure/requirements and staff capabilities; (i) a metadata system

that provides adequate information on the data in the database; (j) ability to allow networked/remote access – linking to network and web servers.

122 A major system will require substantial and expensive technical support, user training, and often bespoke tool development.

3.8.3 Data Display and Reporting

123 All data management should aim at having flexible functions for displaying and printing out data and information in tables, graphs and formatted reports (macros). Systems should also include an interrogation facility to provide output as requested by users. Geographical information systems (GIS) include useful applications in a flood forecasting and warning system, having extensive facilities to assimilate and present data in a spatial context. The ability to map and display information quickly enables a more effective understanding to take place. Spatial data useful in a flood forecasting and warning system include maps of monitoring units digital elevation models (DEMs), isohyets of rainfall, alarm signals and flooded areas, etc.

124 The primary purpose of a flood forecasting and warning service is to provide relevant information at critical times, which has importance as reference. Flood warning organizations should produce post-event reports, which cover both the meteorological and hydrological aspects of an event, along with the operational actions, results, impacts and lessons learned. These reports are internal to the operating organizations and serve as a means of evaluating performance. When major events occur, such reports may form part of a much larger national impact review to top-level central government, e.g. as in the UK following major floods in 1998, 2000-01 and 2007. Some flood warning organizations also produce an annual report as a matter of routine, e.g. the Flood Forecasting and Warning Centre in Bangladesh. This not only serves to review events and performance over the flood season but serves to establish a historic comparison of flood magnitude and impact.

3.8.4 Data Dissemination

125 Data are not only useful within the flood forecasting and warning unit, but also serve a range of decision makers (sometimes referred to as “professional partners”). Data and information has to be of good quality, clearly presented and readily available to a range of users. Many users will not be specialists in the disciplines that collect and manipulate data, so the needs of users and the means of information presentation are important considerations.

126 Potential external users of flood forecasting and warning data include staff of other government departments, public and private infrastructure managers, civil contingency and emergency services and high level government decision makers. This wide range of potential users will have variable information requirements, with some having need solely for data from a single point on a single river and others requiring data over a region, a whole country or even groups of countries in the case of trans-boundary rivers.

127 The vital items of information to be passed on to users are: (a) where will it flood; (b) when will it flood; (c) how large will the flood be; and (d) how long will the flood last. Institutional issues have to be taken into account, including data sharing, public information policy and intellectual property rights. Some countries may apply restrictions to mapped information, with others

applied to the availability of data that may have legal liability issues. Trans-border sensitivities may also affect availability.

128 The type of data disseminated ranges from formal statements made to press and government departments, pro-forma warnings to professional partners formulated jointly according to internal procedures and standing orders, media briefs and warnings, etc. These require rapid conversion of forecast and warning information into a number of formats for onward transmission. Transmission can be by telephone, fax, courier, email or website. Each medium has its advantages and disadvantages in terms of reliability, manpower needs and accessibility, and should be planned for accordingly.

3.9 Available Technological Options

129 Development of flood forecasting and warning capabilities over the last couple of decades has been largely brought about by the rapid advances in electronic observation, telemetry and computing power. This evolution has produced a range of new techniques that include remote sensing, numerical weather prediction, geographical information systems (GIS), and the interfacing of models and data feeds. Many of these techniques are already operational in developed countries, and may not be strictly considered emerging technologies.

130 The choice of technology should always be driven by client needs. Technological alternatives should be assessed according to a balance between the potential reduction in flood damage from an improved quality of forecasting and the cost of the technology needed to gain that improvement. This approach can often be difficult to implement in practice, as there are many other considerations that dictate the choice of the eventual forecasting system used. Nevertheless, in principle the need to achieve this balance should guide decisions concerning the choice of technology as far as practicable

3.9.1 Remote-Sensing

131 Flood forecasting and warning is becoming more reliable and accurate with introduction of remote sensing technologies such as radar and satellites.

132 **Radar:** Radar estimation of rainfall is widely used and is not strictly “emerging”. Radar provides an areal indication of rainfall, and so provides a better distributed measurement than from point rain gauge measurements, with the output lending itself well to use in grid based models. There are a number of limitations in measurement accuracy such as range, attenuation of signal and calibration, but second-generation radar instruments, particularly Doppler radars, have overcome some of the attenuation problems. Smaller radar instruments (C and X-band radars), sometimes portable, are useful for local monitoring, especially in urban areas. The combination of radar with NWP used in short lead time forecasting models has resulted in a considerable scientific advance, allowing prediction of cell development and decay as well as trajectory. There are two other persistent problems relating to radar, the first being cost and the second being the means of transferring radar information from purely visual to digital inputs.

133 **Satellite:** Currently 28 space agencies along with 20 other national and international organizations participate in Committee on Earth Observation Satellites (CEOS) planning and activities. The

NASA satellite monitoring programme produces both real-time and research-merged 3-hour global precipitation products available on an ftp server for public access. However, this service requires considerable resources to support ground validation sites and research. The capabilities of geo-stationary satellite systems have improved steadily, providing more rapid updating (time scales shorter than 30 minutes) and increasing spatial resolution. Rainfall estimation from geostationary satellite platforms uses infra-red **(IR)** sensing based on the relationship between cloud-top growth and surface precipitation, and is best for convective rainfall.

134 Combined systems of polar orbiting and geo-stationary satellites may offer improved rainfall estimation capabilities over the next several decades. These systems may be particularly useful for large river basins with poor rain gage networks and no radar coverage. Useful rainfall estimation from polar orbiting platforms is well demonstrated by the Tropical Rainfall Measuring Mission **(TRMM)** satellite, updating at 3-hour intervals. The TRMM satellite contains precipitation radar in addition to microwave and IR imagers and various outputs of rain accumulations and potential flood and landslip risk.

3.9.2 Numerical Weather Prediction (NWP)

135 Major meteorological services are now using complex atmospheric-ocean models to produce numerical weather prediction **(NWP)** in their forecasting services. NWP has been widely successful in improving both the accuracy and the lead time of weather forecasts, and has also improved precipitation **(QPF)** forecasts.

136 NWP using global wind, temperature and humidity profiles at 20-50km spatial resolution and 1km vertical resolution are required 3-6 times hourly to initialize numerical weather prediction models. Models at this scale are useful for larger (synoptic) scale events. For convective rainfall and small-scale fluvial events, NWP requires a much smaller grid, 5km, and frequent updating, 30 minutes. Running NWP suites requires massive computer power, and along with the high level of data requirements makes this a high-cost, high-investment demand on governments. Only a few NMSs are capable of obtaining this level of support.

137 There is scope, however, for individual regional and local scale models (Local Area Model or **LAM**) to be set up at a national or basin scale, using data feeds and boundary conditions from an existing General Circulation Model **(GCM)**.

3.9.3 Geographical Information Systems (GIS)

138 The use of GIS in a flood forecasting and warning system can provide a wide range of visualisation products, containing far more information than basic mapping applications or text descriptions. GIS uses spatially-related data sets and relational databases to provide successive layers or overlays of information, e.g. the identification of key infrastructure in relation to spatial flood risk. The GIS facility has to be "populated", and gathering appropriate data sets is a significant undertaking in itself.

139 The most important data set in relation to flood warning is the accurate representation of the land surface – usually defined as a digital terrain model **(DTM)**. These can be derived from digitising contour maps, but will lack accuracy. The most appropriate method is by digital airborne survey, using light detection and ranging **(LIDAR)** or synthetic aperture radar **(SAR)**, giving the required

levels of vertical accuracy to 1m or less. High resolution DTMs are a key requirement for providing accurate inundation forecast maps. LIDAR is also being used to identify problematic flood risk areas in constricted urban areas in the UK. The accuracy of LIDAR is sufficient for identifying small, low-lying areas where flood waters accumulate and for detailing flow paths.

4 ORGANIZATION OF FLOOD FORECASTING AND EARLY WARNINGS – OUTREACH TO USERS

4.1 Identification of End-Users and their Requirements

140 The fundamental purpose of warning is to improve safety and reduce damages by communicating information to those at risk so that preventive and protective action can be taken. Warning enables individuals and communities to respond appropriately to a major flood threat in order to reduce the risk of death, injury and loss of property.

141 There are normally several layers of interaction between the organization that issues flood warnings and the various agencies having to perform different tasks in dealing with potential or actual impacts. In many cases, each organization concerned will implement its own operational system during a flood. It should also be noted that the extent and detail of involvement of each organization may vary according to the severity and stage of development of the flood. It is the role of over-arching organizations, e.g. emergency planning ministries or high level, central government agencies, to establish how these links operate; this is not the responsibility of the flood warning organization.

142 Typically, an organization will issue warnings both to its internal staff and to other government departments, the press and media and the public. Where the issuing organization is part of a water management structure, the internal warning prepares staff for other flood mitigation actions. These include:

i manning an incident control centre;

ii placing field observers on a heightened level of reporting;

iii alerting emergency maintenance and repair teams in case of damage to flood defence infrastructure;

iv preparing public/media relations staff with the necessary information on the incident; and

v ensuring that electronic data and information media, e.g. a publicly available internet site, is regularly updated.

143 External warnings are usually issued to:

i other government departments involved in flood and emergency management;

ii local government authorities, e.g. town and district councils;

iii emergency services, particularly police, fire brigade, and in extreme cases, the military;

iv NGOs involved in relief and rescue, e.g. Red Cross/Crescent, Oxfam, USAID, etc;

v public information, press and media; and

vi priority individual premises.

4.2 Flood Early Warning

4.2.1 Areal Definition of Early Warnings

144 Flood warnings need to be specific to particular catchments and reaches of rivers, although early stage warnings can be defined over a geographic area where a number of rivers may be affected. Flood behaviour in a river, either with floodwaters moving downstream or with lower reaches being affected by high tides or drainage congestion, lends itself to arranging flood warnings on the basis of river reaches.

145 The areal definition of warnings must also be suitable from the point of view of incident management and operations. This entails a certain amount of hierarchy for organizational areas, the most local being where warnings and on-the-spot action can be co-ordinated, e.g. with emergency labour teams, liaison with communities and police. For strategic management of resources and co-ordination of larger events, several of the smaller operational areas may be combined. Above this there may be a national organization, which can co-ordinate and report at a high level during a major event.

4.2.2 Lead Time for Warnings

146 There are no hard and fast rules with regard to providing lead time for warnings. Some basic considerations are:

i the size of the catchment and nature of flooding: large catchments with extensive flood-plains are slow to respond, conversely headwater catchments in steep hilly areas afford little potential to provide advance warning of flooding;

ii the nature of the risk and impacts, whether or not evacuation or physical protection (e.g. sandbagging, embankment strengthening) needs to be provided;

iii whether or not staged alerts and warnings are used.

147 The response time in the specific river basin types has been discussed already in **Chapter 3**. Lead times are not only dependent on the appropriate action related to the flood warning, but also to the type of information available.

4.2.3 Meteorological Warnings

148 Meteorological warnings for flood warning purposes are derived from more general weather forecasts. **Figure 8** illustrates the relationship of the time-scale of stages in forecast and warning interactions between meteorological forecasts and flood forecast. It is based on practices in the UK that are coordinated between the Met Office and the Environment Agency flood warning services, but the principles are similar whatever the scale or country.

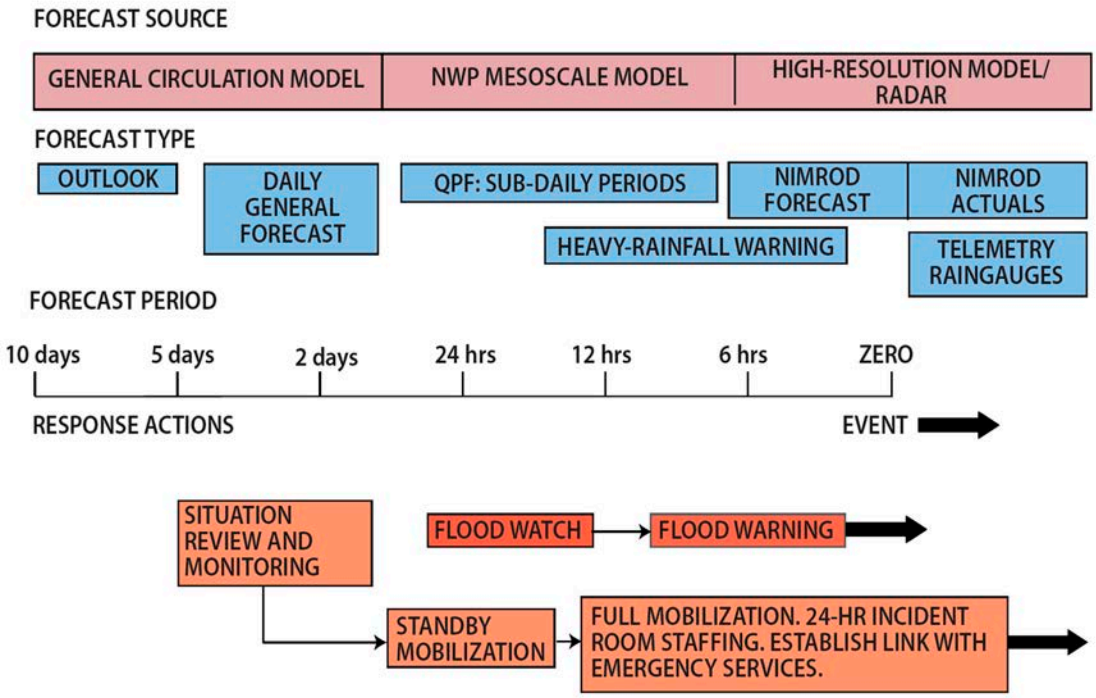

Figure 8 — Schematic of flood-forecasting lead time

149 Long range forecasts, i.e. those covering periods of several weeks or months, are not sufficiently detailed or accurate to be considered as part of the flood warning process. There may be benefits when an area is under a regular annual flood regime, e.g. the Asian monsoon or African inter.tropical convergence zone (ITCZ), where an advance forecast might initiate general preparedness actions. In the Republic of South Africa, for example, the forecast of an El Nino event is used in advance planning by the Department of Water Affairs and Forestry.

150 Forecasts within the five-to-ten-day range now generate a high level of confidence in terms of major meteorological features, e.g. storm tracks. These forecasts are most useful for large basins or areas as indicators of a possible widespread event. The benefit of the forecast is primarily to commence response actions. Under five days, forecasts provide more focused information concerning the locality and severity of an event if made on a regional level. However, information is still insufficient for providing specific local warnings.

151 For lead times below two days, meteorological forecasts based on NWP introduce more detail into the flood warning process. Two-day lead time forecasts of heavy rainfall are important when river levels are already high and when further increases might heighten flood risk. Even in catchments with a response time of less than one day, a forecast for heavy rain can help

the flood warning authority make initial decisions on manning levels, institute preparedness measures for local flood defence activities and issue alerts or early stage warnings to the public.

152 Once an event is imminent, detailed weather forecasts using NWP and radar offer a significant tool to facilitate flood warning decisions and actions. Particular catchments and high-risk localities within the catchment can then receive heavy rainfall warnings.

4.2.4 River-based Flood Warning

153 These are specific warnings based on projections from river observations. As with meteorological warnings, the lead time for the in-river situation is based on size and response time but it is nonetheless a prerequisite that the river system should already be responding to the event before projections are made. On major rivers, e.g. the Nile, the Indus and the del Plata, the progress of severe conditions downstream allow warnings to be made several days in advance.

154 At the lower end of the scale, minimum warning lead time can be established reflecting the capacity available for receiving data and making forecasts, taking into account the time to implement necessary response actions as well. This lower limit is particularly relevant for steep catchments or for catchments in urban areas. Rapid response flooding is sometimes called "flash flooding".

4.2.5 Flood Warnings Activities and Responses

155 **Figure 9** represents the relationship between information, lead time and response in forecasting. The diagram summarizes actions to be taken once the flood is in progress. It covers the period of development of the flood to its peak and then to its recession. Escalation of responses depends on the severity and impact of the flood.

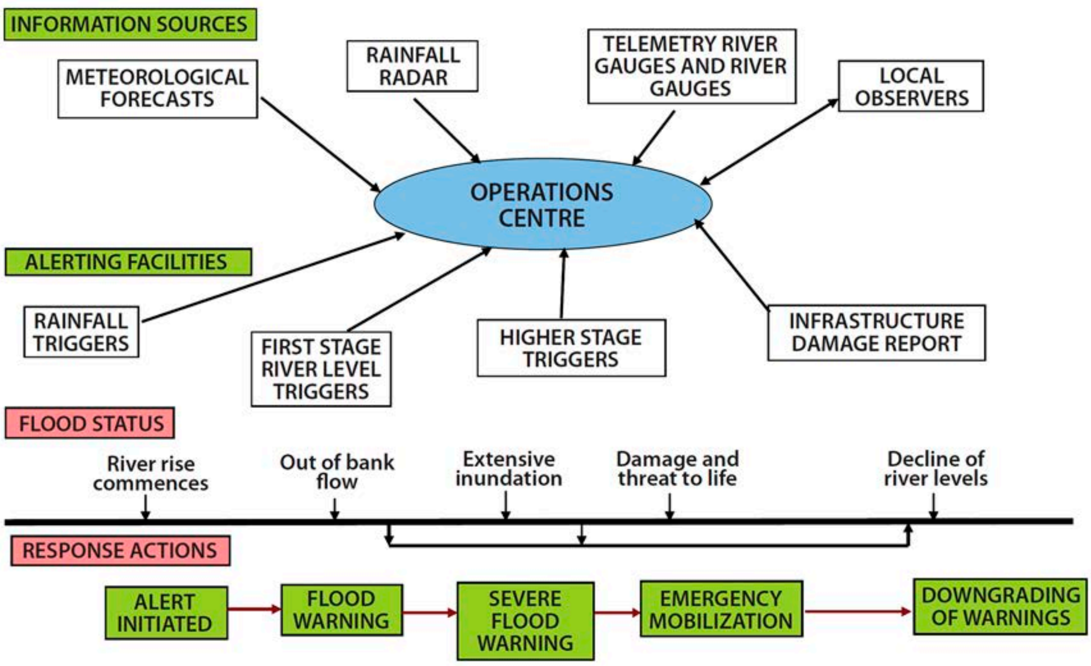

Figure 9 — Flood warnings and responses

4.2.6 Selection of Warning Stages: Rainfall Triggers

156 Both flood forecasts and warnings can be linked to "triggers" associated with critical river levels or rainfall amounts that indicate the approach or worsening of flood states. The triggers provoke certain actions or the provision of information to external users. Triggers relating to rainfall include:

- i accumulations exceeding a threshold in a given time period, for example 100 mm in 12 hours or less (this threshold may need to be changed according to season);
- ii rainfall accumulation and catchment wetness conditions; rainfall intensity exceeding a given rate (particularly important in urban areas where drainage capacity can be exceeded and flash floods can occur).

4.2.7 Criteria for Setting River Level Triggers

157 Triggers must be established by careful study of local conditions. The advice and knowledge of the local community, if available, is therefore important. Triggers should not be arbitrary or standard within an organization, e.g. within 1 metre of "danger" level. Triggers should be related to local conditions and features of particular risk, for example:

- i the level at which water flows out of channel onto the floodplain;
- ii the level of water that submerges areas of land used by livestock, or low lying roads become flooded;
- iii the level where major areas, including residential and business properties and communications, are affected;
- iv the level where depth and velocity combined pose a threat of structural damage and a danger of loss of life.

158 In assigning suitable forecast triggers for urban flooding, the criteria used should be based on a forecast that would normally result in a high risk of actual flooding taking place (at least a 30% chance of occurring). The general arrangement of flood warning stages is shown in **Figure 10**. A schematic of the forecast and warning relationship from rainfall forecast to downgrading a warning is illustrated in **Figure 11**.

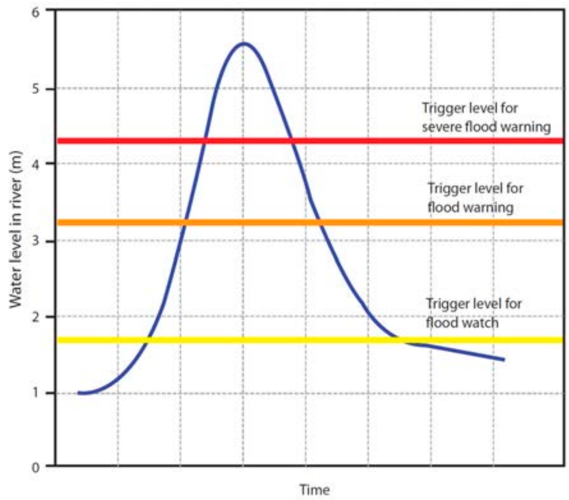

Figure 10 — Arrangement of trigger levels for various flood warning stages

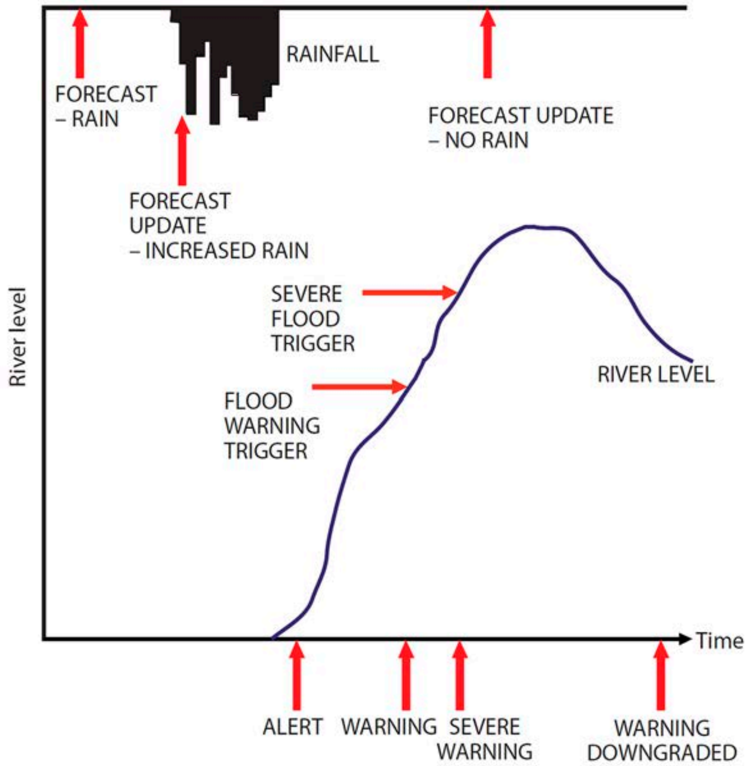

Figure 11 — Flood forecasting and warning schematic

159 **Figure 11** shows the relationship between information, lead time and response. Throughout the process, comparisons of observed and forecast information must be maintained in order control response actions. This is important for liaising with emergency services and other agencies outside the flood monitoring organization and to give sufficient time to escalating levels of response or to downgrading status.

160 Triggers for flood warning should be devised so that they are not reached too frequently. Too-frequent triggering can cause unnecessary responses or disruption, and can engender a negligent attitude in operators and the public that results in warnings not being heeded. Too many false alarms can create the same problem. A crucial balance has to be struck between taking too many precautions and taking too few out of fear that particular warnings may be "wrong". A phased alert-warning system is recommended, one that allows the alert-warning situation to be downgraded if conditions improve or forecasts change.

4.3 Presentation of Warnings to Users

161 A flood warning service may be highly organized and integrated on a technical and administrative level, but nonetheless flood perception and response can vary significantly. Warnings are channelled in two main ways: through official agencies and through the public. Both ways require that the technical information used and produced by the flood forecasting and warning services be passed on to users in non-technical and unambiguous terms. Effective dissemination is as important as the technical methods of producing forecasts and warnings, and careful assessment of community needs is essential if the system is to achieve good results.

4.3.1 Flood Warning Symbols

162 Following serious flooding in England and Wales in 1998, concern was expressed at the lack of effectiveness of warnings. A top level review found that the colour codes then in use were confusing and misunderstood "by nearly all who received them". Colour codes (e.g. yellow, amber, red) or symbol codes, e.g. cones or flags, may be understood by professionals directly involved but by few others.

163 The system introduced into England and Wales as a result was a combination of a symbol using a simple illustration and specific written instructions. Information about the symbols and instructions was disseminated through a comprehensive publicity campaign to raise awareness. The symbols and explanatory instructions are shown in the table below. These types of symbols are generic and therefore use typical representations of local houses. In Bangladesh, Mozambique and other countries other kinds of visual representations have been devised and are meant to convey the message to non-literate people.

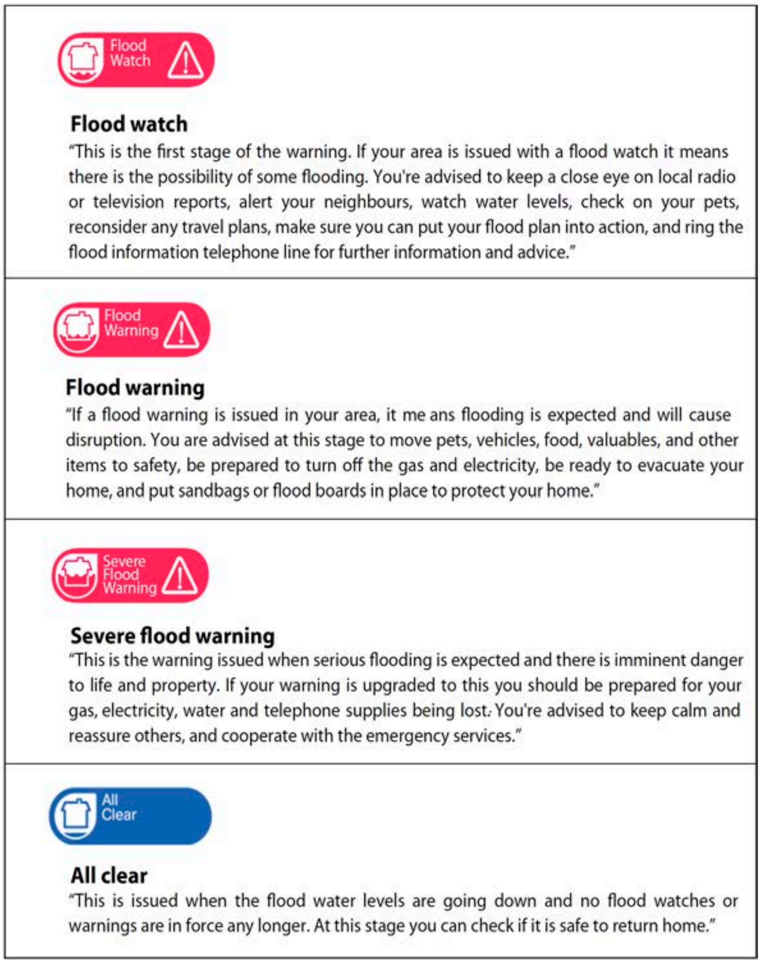

Figure 12 — United Kingdom flood warning symbols and the instructions that accompany them

4.3.2 Examples of Flood Warning Information Outputs

164 A wide range of information formats is used by NMHSs across the world. These can be text- or map-based, and they are being made increasingly available to the general public via websites

as well as by professional partners. In order for a developing flood forecasting and warning service to be aware of and incorporate the range of information and presentation formats in use, the WMO Manual provides a selection of flood forecasting and warning outputs available from national flood warning service websites.

165 The warning message is the critical link between flood forecasting and interpretation on the one hand and taking protective action on the other. It must be 'user friendly'. This means it should explain what is happening and what will happen, where, how the flood will affect the recipient of the message and what he or she can do about it. The message must come from a credible source (such as authorized government agencies), be informative and persuasive and be clearly understood by those receiving it. The message may be either in written form or communicated verbally.

166 A precondition for effectively-designed flood warning messages is a detailed knowledge of the flood problem. This includes knowledge of the physical dimensions of flooding and of the communities at risk, as well as an understanding of how those communities will be affected by flooding. The characteristics of the flooding, the nature of the community and the interaction between flood and community should influence the way warning messages are constructed and disseminated. The particular physical characteristics of flooding relevant to flood warnings include:

- i the time when the floodwaters will arrive or reach certain heights;
- ii the time when the flood will occur (e.g. during the day or late at night);
- iii how long the flood is expected to last;
- iv where the water will go (i.e. in terms of areas that may be inundated);
- v the depth and velocity of the expected floodwaters; and
- vi other factors which may affect safety.

167 Flood warning messages should be delivered in ways that are designed to motivate or arouse. This can be done by using 'arresting' language, or by having messages accompanied by a siren or other alarm. The tone of messages is important. As far as possible, messages should:

- i be positive rather than negative, saying what to do rather than what not to do (e.g. "stay at home" rather than "don't leave your home");
- ii suggest action rather than inaction (e.g. "raise your belongings" encourages definite action); and
- iii invite sociability rather than isolation (Social interaction is part of the process of message confirmation, and messages like "advise your neighbours" or "check to see whether your neighbours need help" encourage sociability and help ensure people are assisted where necessary and are in touch with others.).

4.3.3 Warning Information Contribution to Flood Response

168 Large numbers of people unable to access the internet, especially in communities in remote areas, may not be able to receive warnings. The forecasting authorities need to be aware of remote communities that are at risk. Although it may not be necessary to prepare individual forecasts for these locations, these people need to understand the effects of severe conditions

in their particular localities. Responsibilities need to be clearly defined so that the lower tiers of administration and the emergency services have established links with communities in remote areas. This should include:

- i local radio, which should be supplied with clear, accurate information;
- ii making use of appointed community wardens having direct two-way radio or mobile telephone access to warning agencies and emergency authorities;
- iii local means of raising alarms, for example church bells, sirens sand loud hailers, the latter being the responsibility of selected individuals or wardens, who need to be provided with equipment and transport such as motor cycles or bicycles; and
- iv "sky shouts" from emergency service helicopters.

169 It is necessary to ensure that the local maps used by emergency services and those used by the central forecasting and warning agencies are compatible with each other and up-to-date. If local communities do not have flood risk maps, it is important to preserve flood marks on key buildings in order to indicate possible impacts. In parts of Bangladesh, flood marks are recorded on roadside milestone that indicate the impact of floods on access roads. In places where major floods are not a regular occurrence, recording maximum historic floods is also important, since major floods may not have occurred during the lifespan of current residents. In Dresden, flood level marks going back over two centuries were of great value in referencing the 2002 floods on the River Elbe within a long a time series.

4.4 Flood Alert Systems

170 Local flood watch arrangements are very important both for local community preparedness and for allowing local watchers to provide early information to the authorities. Quite often, localized flooding can occur without being picked up by monitoring networks. Local arrangements may include the following:

- i Providing simple rain gauges and river level staff gauges to be read by an appointed individual. Rain gauges are particularly important in flashy catchments where flooding can occur quickly and where maximum warning time is needed;
- ii Keeping watch on the river level and embankment conditions in the local area. The frequency of the river and embankment watches should be increased as the flood height approaches and crosses the critical level;
- iii Observers who are authorized to give local warnings;
- iv Observers who provided with means of communication, for example two-way radio, loud-hailer.

4.4.1 Local Flood Warning Systems

171 Local Flood Warning Systems **(LFWS)** can be divided into two basic categories based on how gauge data is collected, that is, either manually or automatically. In both cases the goal is to detect precipitation events that exceed thresholds so that there is sufficient lead time and prior preparation to minimize the effects of the ensuing flood. Determining the most effective type of FWS for a community is a complicated problem. The type of system used will depend on the familiarity of the community with the technological options and its comfort in using them.

172 **Manual LFWS:** Many of the local FWS in operation today are manual self-help systems that are inexpensive and simple to operate. They are deployed, maintained, and utilized by a local group. The manual self-help system is comprised of a local data collection system, a community flood coordinator, a simple-to-use flood forecast procedure, a communication network to distribute warnings and a response plan. More sophisticated automated rain gauges may be necessary in remote areas or in other situations where enough reliable observers are not be available. Stream gauges also vary in sophistication, from staff gauges to Limited Automatic Remote Collection **(LARC)** systems, radios, etc.

173 A NMHS centre can sometimes provide the community FWS centre with a simple, easy-to-use forecast procedure. This procedure normally consists of tables, graphs or charts that use observed and/or forecast rainfall and an index for flood potential to estimate a flood forecast. These indices for flood potential are determined by the NMHS and are provided to the communities. Although manual gauge reports are less prone to errors, they are also less able to provide high temporal resolution for situations with intense rainfall rates. It is typically much easier to obtain rainfall rate information or short-duration accumulation from automated gauges.

174 **Automated LFWS:** In the past two decades, a substantial growth in technology in data collection and computer systems has resulted in the creation of automated flood warning systems. Three of the more prominent automated LFWS are flood alarm systems, ALERT, and IFLOWS. An automated LFWS is composed of sensors that report environmental conditions to a base station computer using an observation platform communication protocol and a second communication protocol to send information between the base station and other computer system(s). An automated LFWS has either a stand-alone or a network configuration.

175 Automated LFWSs have been designed, developed and implemented by NMHS and other government agencies, including state and local governments, and by private vendors. They vary in design, capability, and operation. A community must assess its needs to determine the level of sophistication (and associated system acquisition and maintenance costs) required. Automated system operations may vary from a simple flash flood alarm gauge that audibly announces imminent flooding to a continuous computerized analysis of observed precipitation and stream flow coupled with a hydrologic model to forecast flood levels.

176 A flood alarm system consists of a water-level sensor(s) connected to an audible and/or visible alarm device located at a community agency with 24-hour operation. Water levels exceeding one or more preset levels trigger the alarm. If the system is configured to detect two preset levels, the rate of rise can be determined. The water-level sensor(s) is set at a predetermined critical water level and is located a sufficient distance upstream of a community to provide adequate lead time to issue a warning.

177 **Automated Local Evaluation in RealTime (ALERT):** The ALERT system was initially developed in the 1970s by the California-Nevada River Forecast Center in Sacramento, California (U.S. Department of Commerce. 1997a), and consists of automated event-reporting meteorological and hydrologic sensors, communications equipment, and computer software and hardware. In its simplest form, ALERT sensors transmit coded signals, usually via very high frequency **(VHF)** and ultra high frequency **(UHF)** radio, to a base station, often through one or more relay or radio repeater sites. The base station, which consists of radio receiving equipment and a

microprocessor running ALERT software, collects these coded signals and processes them into meaningful hydro-meteorological information. Processed information can be displayed on a computer screen according to various preset criteria, with both visual and audible alarms activated when these criteria are reached. Some systems have the capability of automatically notifying individuals or initiating other programmed actions when preset criteria are exceeded. Also, the observed data can be ingested into a rainfall-runoff model to produce forecasts. The ALERT User's group is an excellent source of learning about ALERT technology (http://www.alertsystems.org).

178 **Integrated Flood Observing and Warning System (IFLOWS):** As noted by (Gayl 1999) and the *U.S. Weather Service Hydrology Handbook No. 2* (1997b), the U.S. NWS supports a computer software and network application designed to assist state and local emergency services as well as NWS offices in detecting and managing flood events. The software receives and disseminates data from a network of real-time weather sensors, primarily rain gauges, and has the ability to display gauge data, set alarms, and exchange text messages with other network users. The system as a whole is known as the Integrated Flood Observing and Warning System **(IFLOWS)**. The system is quite dated but is useful here as an example of an approach that has been successful.

179 The website for IFLOWS is http://www.afws.net. IFLOWS can be viewed as a wide-area network of ALERT-type systems with enhanced, full, two-way communications capability (voice, data, and text). ALERT systems are normally preferred as stand-alone systems. The potential developer of an LFWS, in the design phase, should consider the network configuration with its associated area-wide capabilities and costs as well as the stand-alone configuration with its local capabilities.

4.5 Warning and Society

180 A flood warning service may be highly organized and integrated on a technical and administrative level, but perception and response are always dependent on social structures and frameworks. These can be highly variable and often unpredictable. The goal at the community level is that warnings should be received by all individuals. The way in which messages are disseminated in communities will depend on local conditions, but may include some or all of the following:

- i Media warnings;
- ii General warning indicators, for example sirens;
- iii Warnings delivered to areas by community leaders or emergency services;
- iv Dedicated automatic telephone warnings to properties at risk;
- v Dissemination of information about flooding and flood conditions affecting communities upstream. One approach to achieve this is to pass warning messages from village to village as the flood moves downstream;
- vi Keeping watch and giving regular information about the river level and the embankment conditions in the local area. The frequency of the river and embankment watches should be increased as the flood height increases and crosses the critical danger level;
- vii A community-based warning system to pass any information about an approaching flood to every family.

4.5.1 Media Awareness of Flood Warning

181 Radio and TV broadcasts are vital participants in the flood warning process. Newspaper coverage of flood events is also important. The relationship between the forecasting and warning services and the media must be managed carefully. Reporters and broadcasters are not technical specialists, and their basic aim is to publicize a "story". Mistakes and failures, for example in severe weather forecasts, flood alerts, breakdown in emergency response, fatalities, etc., will be emphasized, but the success of an operation is not similarly highlighted as "good news". Media have a fondness for their own emotive terms, e.g. overflowing rivers – "burst their banks; flash floods – on-rush of waters; heavy rainfalls "torrential"; severe flooding unprecedented or "the worst in living memory"; or unusual events - "evidence of climate change".

182 Major NMSs and flood warning services operate well-organized press and media units, both to respond to media queries and to be pro-active on media releases involving specialist content. These units are required because most technical specialists are not well experienced in dealing with the media. The latter may put their own interpretation on a technical statement or take statements out of context. One approach is to select technical officers selected for media contacts and give them specialist training in ways of presenting and writing press briefs, public awareness material, etc. Another is to select media officers who have a background in media work and train them in the basics of meteorology and hydrology. This may be more effective than training a technical specialist to deal with media relations. Weather channels proliferate on television and radio in the USA. At the other extreme, the British Broadcasting Corporation (BBC) uses only qualified UK Meteorological Office staff.

An example of an assessment of the need for a local flood warning system in the United States

183 In the United States, the Office of Hydrologic Development, part of the NWS, has developed a comprehensive programme to support local flood warning activities under the Community Hydrologic Prediction System (CHPS). The basic goals of CHPS are to:

- i reduce the loss of life and property damage caused by flooding; and
- ii reduce disruption of commerce and human activities.

The techniques for reaching these goals are:

- iii improving and maintaining an effective communication system between "need-to-know" agencies and individuals;
- iv inducing local community involvement and response planning;
- v educating the public to respond to flash-flood forecasts and watches and warnings and to act appropriately;
- vi promoting effective flood-plain management;
- vii minimizing the response time from flash flood warning issuance.

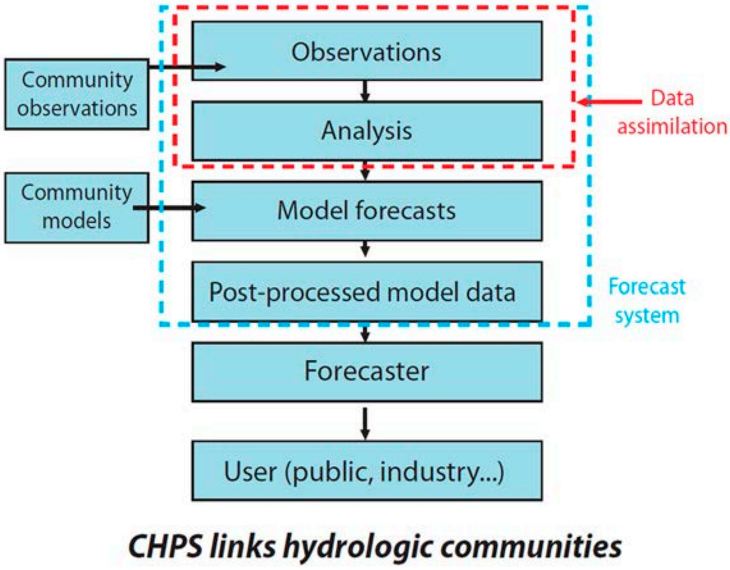

Figure 13 — The role of CHPS in the United States

184 Many of the local flood warning systems in operation in the United States today are manual self-help systems that are inexpensive and simple to operate. They are integrated into the overall forecasting and warning system, as shown in **Figure 13**. The self-help system comprises a local data collection system, a community flood coordinator, a simple-to-use flood forecast procedure, a communication network to distribute warnings and a response plan. It has been found that the simplest and least expensive approach to data collection is to recruit volunteer observers to collect rainfall, stream- and river-stage data. Inexpensive, plastic rain gauges are available from the NWS for volunteer observers who report rainfall amounts to a community flood coordinator. The flood coordinator maintains the volunteer networks.

185 More sophisticated automated rain gauges may be necessary in remote areas or in situations where observers are not available. Stream gauges also vary in sophistication, ranging from staff gauges to automatic telemetered gauges.

4.6 Flood Warning Effectiveness and Human Psychology

186 In many situations and over a wide range of social conditions, flood warnings often fail to be effective. There are many reasons for this, including:

i inhabitants may be unwilling to leave their property, belongings and livestock out of fear of looting and vandalism;

ii the actions of neighbours or weather may contradict the official warning (people often seek confirmation of a flood event before they act);

iii some people are averse to following the dictates of authority and may ignore official advice;

iv some people cannot heed warnings because they may lack the physical or mental capacity to respond, or they may be absent from their dwellings;

v some of those at risk may not be worried about flooding until they suffer a loss; and vi populations at risk will be very diverse, which may mean that they have different priorities, languages and levels of understanding of the flood warning.

187 Dissemination systems need to be periodically reviewed to see if material and arrangements are still appropriate. In particular, warning delivery, receipt and action performance needs to be reviewed after each major event.

188 **Community based Early Warning System:** Community connections form the relationships necessary to develop, implement and maintain an effective end-to-end early warning system. A flood warning centre can only be successful if the warnings it produces reach individuals at risk and are easy to understand, resulting in appropriate responses. To assure that warnings are most effective, the staff at a centre must establish trusted partnerships among international organizations, governmental agencies, community leaders and organizations, businesses and local citizens prior to issuing a warning.

4.6.1 The Persuasive Communication Continuum Model

189 Effective education and outreach must be based on a thorough understanding of the processes that individuals go through when they make decisions about modifying their personal behaviour. Warning specialists must understand human behaviour in order to design and implement better warnings. **Figure 14** shows the key stages in the continuum of persuasive communication that leads to behaviour change. The success of a warning rests on public/individual awareness, understanding and acceptance of the risk.

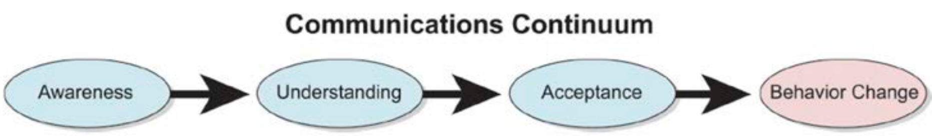

Figure 14 — Stages of persuasive communication (Source: The COMET Program)

190 For example, in order to motivate residents to heed evacuation warnings, the residents must first be made aware of their risk. Second, they must be helped to understand the impact an event may have on their family and community. Third, they must come to accept the idea that not following a warning message can result in injury or death. Finally, they must take action and heed the warning to evacuate. If the intent is behaviour change or action, then outreach must focus on moving the public through the initial stages of awareness, understanding, and acceptance.

4.6.2 Community Preparedness

191 Community preparedness can be thought of as the capacity of a community to respond to the consequences of an adverse event by having plans in place in advance so that people know what to do and where to go if a warning is issued or a hazard observed. This result can be achieved by developing programs like the United States' Storm Ready Program (see www.stormready.noaa.gov/) and community-based disaster risk reduction programmes that exist in many developing countries where communities establish plans, enhance communications and heighten awareness among their citizens. This type of program can increase resilience to flood and other hazardous events, reduce economic losses and shorten recovery periods.

192 Outreach and communication with the public is crucial to its understanding of the nature of the hazards, the risks to personal safety and property and the steps required for reducing those risks. Key components of a community preparedness program include:

- i raising public awareness and effecting behavioural change in the areas of mitigation and preparedness;
- ii deploying stable, reliable, and effective warning systems; and
- iii developing effective messaging for inducing favourable community response to mitigation, preparedness, and warning communications.

193 Safer Communities is a series of Asian Disaster Preparedness Centre (ADPC) case studies that illustrates good practices in disaster preparedness and mitigation undertaken either by governments or by non-governmental agencies to reduce the vulnerabilities and risks to communities living in hazard-prone areas. The series aims to provide decision makers, development planners, disaster management practitioners, community leaders and trainers with an array of proven ideas, tools, policy options and strategies derived from analyses of real-life experiences, good practices and lessons learned in the Asia and Pacific region.

194 Safer Cities, a similar ADPC volume of case studies, illustrates how people, communities, cities, governments and businesses have been able to make cities safer before disasters strike. It emphasizes the significance of setting up an operational early warning system and evacuation plan as a mechanism for drawing people together for collective action towards building safe and resilient communities. The approach calls for identifying viable preparedness and mitigation measures, Community-Based Disaster Risk Management (CBDRM) and good governance. Lessons learned include the following:

- i Early warning systems are more effective if individuals and groups understand the benefits of such systems;
- ii Community involvement in EWS development leads to systems that respond more quickly;
- iii Drills can test plans and show strengths and weaknesses;
- iv Simulation exercises helped each sector involved share its knowledge and skills in preparedness and response by allowing others to witness, impart comments and eventually replicate this kind of endeavour.

4.7 Capacity Building and Training

195 The activity of the flood forecasting unit staff is likely to be divided between their operational duty and that of the full time establishment post. Even where there is dedicated flood forecasting and warning, routine tasks are very different from operational ones. Developing a flood forecasting and warning unit within existing organizations will require selecting from a range of skills. The activities of staff working in flood forecasting services fall into four main categories:

- **Operational activities:** analyzing the hydro-meteorological situation and making forecasts using simulation models;

- **Modelling:** staff members determine the requirements for designing simulation tools that may vary greatly depending on the types of basin being studied. Prior calibration and operational implementation are technically complex operations;
- **Hydrometry:** ranging from data collection to its input to the operating and archive databases. This field also covers data transmission and data quality control;
- **Informatics:** ensuring that equipment and real-time applications are functioning correctly 24 hours a day. Information technology (IT) specialists are also responsible for providing and implementing all output formats as maps, diagrams and text.

196 All newly-recruited and existing staff must therefore be trained in new concepts and in the latest techniques, while newly-recruited staff also receive training adapted to their new job.

4.7.1 Training Requirements

197 A career structure within a flood forecasting and warning unit should encourage continuing professional development (CPD), either by obtaining a specialized post-graduate degree or a further qualification from a professional body, e.g. an institution of professional engineers, or training as a Chartered Meteorologist (UK). France offers certification within a coherent training scheme irrespective of an individual's particular background. A particular technical certification in computer operation, for example, is considered to be equivalent to being an instrument technician. In the UK, a system of National Vocational Qualifications (NVQs) has been introduced that covers meteorological skills.

198 **Training and continuing education:** The skills required in each discipline or specialist activity can change over time, mainly because of scientific and technical advances but also because of changing service requirements. New equipment, e.g. downloading to portable data units or lap-top computers, will require staff retraining, which must be part of procurement contract.

199 Staff in a flood forecasting and warning organization should have access to regular training programmes, either to complete their basic education or to maintain and develop new skills. Training courses in core activities, for instance flood forecasting, meteorology, hydrometry, hydrology and hydraulics, administration, public awareness and environmental responsibilities, are important. These programmes may be offered annually to allow new staff to be trained.

4.7.2 Capacity Building Options

200 Key technical staff such as instrument technicians, observers and hydrometric technicians should receive several weeks of on-the-job training provided either by visiting specialists or by spending a period of time with suppliers or with an organization already using the relevant equipment. On the basis of their experience, trained staff should be encouraged to provide training internally to their staff in their home organizations. Senior professionals and management can benefit from study tours where they spend time with organizations currently using advanced techniques.

201 **Training the trainers:** Another aspect of capacity building and of motivating staff members within the organization, this approach has been successfully applied in Papua New Guinea and Bangladesh. There, senior technical officers spent time with the New Zealand flood warning service and then returned to provide training inside their national hydrological and flood warning services.

202 **Self-study and distance learning:** Correspondence courses through remote learning centres (Open University) are becoming increasingly available from web-based sources.

203 **Training through simulation exercises:** A few hydrological services use simulators of their flood forecasting software, which allow professionals to train and become familiar with new technologies and new practices by testing "what if" scenarios.

204 **Operational training of personnel in service delivery:** The means by which the flood forecasting and warning units deliver their services are best implemented through the staff structure, where senior, more experienced members pass on knowledge to newly-recruited staff. This may require operational training at several levels:

– Technical skill training to keep up-to-date with latest developments. New equipment and technologies;
– Familiarization training for different units within the organization. Field Officers made aware of data processing staff needs, etc;
– Training for the whole unit, including internal and joint exercises;
– Training for interfacing with other organizations, including technical training in associated fields. Communications skills, e.g. for press and media briefings.

205 **Training for co-operation with other organizations:** A useful example of this is to teach flood forecasting staff to understand the content of meteorological information. Several courses have been produced by the UK Met Office to train Environment Agency staff engaged in flood forecasting and warning. The courses were carefully designed, with clearly defined topics and technical content to suit different categories of staff. Course content is intended to meet specific competency levels, and the courses are considered by the Environment Agency to be part of the internal training programme for staff members. Some of the courses are: (a) General Meteorology; (b) Meteorology for Flood Warning Duty Officers; (c) Radar Meteorology and NWP; and (d) Tidal and Surge Forecasting.

4.7.3 Establishing Understanding of Forecasts and Warnings by Users

206 It is essential for flood warning managers to recognize and understand fully the range of user requirements so that flood warning products, data and information can be adapted to meet their specific needs. Catering to a range of users helps improve the esteem of the flood forecasting and warning service, while encouraging investment and sustainability.

207 Some countries place stringent controls on how much public access is allowed to river information. This issue can be particularly important in the case of shared international rivers, e.g. the Ganges and the Brahmaputra between India and Bangladesh and the Limpopo between Zimbabwe, South Africa and Mozambique. For humanitarian reasons, every effort should be made to facilitate trans-border information sharing on flooding to countries downstream.

208 A wide range of written, diagrammatic and mapped warnings are produced by flood forecasting and warning agencies. In order for warnings to be better understood, principal users such as local government authorities, emergency services and relief agencies should receive training on the content and use of forecasts. During serious events, briefing meetings are helpful.

5 EXAMPLES OF NATIONAL FLOOD FORECASTING AND EARLY WARNING SYSTEMS

5.1 National Flood Warning System

209 The type of flood warning service available varies greatly from country to country, and a location may receive warnings from more than one service. However, hosting publicly available websites is becoming common in both developed and developing countries. Some examples are given in the table below.

Table 4 — Examples of national flood warning service websites

Country	*Operating agency*	*Web agency*	*Outputs*
United Kingdom	Environment Agency	http://www.environment-agency.gov.uk/homeandleisure/floods	– Information statements – Location maps
Australia	Bureau of Meteorology	http://www.bom.gov.au/australia/flood/	– Information statements – National, regional and catchment maps
Bangladesh	Bangladesh Water Development Board	http://www.ffwc.gov.bd	– Information statements – National maps – Station water level plots and forecasts
United States	NOAA National Weather Service	http://www.nws.noaa.gov	– Information statements – National, regional and catchment maps – Station water level plots and forecasts

Similarly, examples of national flood forecasting and warning systems, representing five different continents and both developed and developing countries, are presented in the following sections.

5.1.1 Australia

210 The Bureau of Meteorology provides a flood warning service for most major rivers in Australia. This service is provided with the cooperation of other government authorities such as the State Emergency Service **(S/TES)** in each state/territory, water agencies and local councils. The Bureau delivers this service through Flood Warning Centres and Regional Forecasting Centres in Bureau Regional Offices in each state and in the Northern Territory.

211 The Flood Warning Service provides different kinds of information that depend on the type of flooding and on the flood risk. The range of information, which may vary between states and between areas within a state, includes: an alert, watch or advice of possible flooding, if flood-producing rain is expected in the near future. General weather forecasts can also refer to flood-producing rain.

212 As part of its Severe Weather Warning Service, the Bureau also provides warnings for severe storm situations that may cause flash flooding. In some areas, the Bureau is working with local councils to install systems to provide improved warnings for flash floods. These systems provide warnings of 'minor', 'moderate' or 'major' flooding in areas where the Bureau has installed them. In these areas, the flood warning message identifies the river valley, the locations expected to be flooded, the likely severity of the flooding and when it is likely to occur.

213 In each state, flood warnings and river height bulletins are available via some or all of the following:

i Local response organizations: These include the council, police, and state emergency services in the local area;

ii Bureau of Meteorology: Flood warnings and general information are available directly from the Bureau in each state;

iii Radio: Radio stations, particularly local ABC and commercial stations, broadcast warnings (and bulletins) soon after issue;

iv Telephone recorded information services: Flood warnings are available in some states via a Bureau of Meteorology recorded message service (charges apply);

v Internet/World Wide Web access: The Bureau's home page is www.bom.gov.au

5.1.2 Bangladesh

214 The Flood Forecasting and Warning Centre **(FFWC)** was established in 1972 as a provision of the BWDB Act-2000 to persuade and enable people and organizations to prepare for floods and to take action to increase safety and reduce damage. Flood forecasting in Bangladesh is the mandate and responsibility of the Bangladesh Water Development Board **(BWDB)** and FFWC. The FFWC is fully operational during the flood season, from April to October every year, as directed by the Standing Orders for Disaster **(SOD)** of the Government of Bangladesh. The

FFWC acts as the focal point for co-ordinating with other ministries and agencies such as BMD, DMB, DAE, etc. for flood disaster mitigation and management during the monsoon season.

215 The General Model (GM), developed under MIKE11, was adapted to real time operation in which boundaries were extended up to the Indian border on all main rivers. A supermodel is now in operation at FFWC, covering entire the northern flood-affected area of Bangladesh. The supermodel covers about 82,000 km^2 of the country except for the coastal zone. The area is sub.divided into 107 sub-catchments and includes 195 river branches, 207 link channels and 40 broad crested weirs. The total river length modeled is about 7,300 km.

216 Real time hydrological data (from 86 water level stations and 56 rainfall stations) is collected by SSB wireless as well as by fixed and mobile telephone from the BWDB hydrological network. Water levels for non-tidal stations are collected five times daily at three-hourly intervals during daytime hours from 6:00 AM to 6:00 PM. For tidal stations the data is collected hourly. Rainfall data are collected daily at 9 AM. Data collections at the FFWC are usually completed by 10:30 AM. Limited water level and rainfall data, along with forecasts of upper catchments from Indian stations, are also collected using the internet, e-mail, and are also obtained from BMD.

217 A daily forecast bulletin is prepared covering up to 72 hours for important locations and for region-wide flood warning messages. The bulletins are disseminated to more than 600 recipients including different ministries, offices (central and district level), individuals, print and electronic news media, development partners, research organizations, NGO's, etc., including the President's and the Prime Minister's secretariats. Whenever the forecast river stage crosses the danger line, the concerned field offices and a limited number of key officials are informed using mobile SMS. The flood forecast is intended to alert the public of the predicted water levels three days ahead of their occurrence. With support from the Bangladesh Disaster Management Bureau (BDM), cell broadcasting has begun as of July 2011 for flood warning message dissemination. The instant voice response (IVR) method is used; anyone can call 10941 from Teletalk mobile and hear a recorded Bangla voice message regarding the day's flood situation.

5.1.3 Mozambique

218 Prior to the 2000 flood, Mozambique had no operational flood forecasting and early warning system. With lessons learned from decades of flood disaster and the flooding in 2000, the Mozambique government has emphasized disaster management, early warning systems and community-driven rescue systems. Flood forecasting and early warning in Mozambique is a regional issue. Almost all of its rivers originate in other southern African countries. This situation means that Mozambique must work closely with other countries of the Southern Africa Development Community (SADC).

219 The 1999 floods policy forecasts flood risk, detects and monitors flooding, and puts out flood warnings when necessary, paving the way for a coordinated response. Mozambique has developed strong collaboration among the meteorological services, hydrological services and disaster management teams. The flood early warning system is coordinated by the National Directorate of Water (DNA), together with the National Institute of Meteorology (INAM) and the National Disaster Management Institute (INGC). This collaboration reflects the essential

integration of the hydrological and meteorological information needed to understand and predict floods and to manage an effective response.

220 The National Institute of Meteorology (INAM) is responsible for collecting meteorological data and preparing a range of forecasts – seasonal (October to March), four-day and daily forecasts, while DNA and five Regional Water Administrations (ARAs) are responsible for hydrological data collection and services. In times of high river flows or severe weather events, the agencies provide monitoring and forecasting information three times a day according to the protocol managed by the National Institute for Disaster Management (INGC). Regional Water Administrations work at the river basin level, monitoring water levels and providing data to INAM. INAM uses river basin data along with data collected from meteorological stations across the country, from radar equipment and from satellites to update forecasts periodically.

221 The Regional Water Administrations issue flood warnings to district governments and local authorities as well as to the media (radio, television and newspapers). District governments and local authorities, in collaboration with the Red Cross and other non-governmental organizations (NGOs), are responsible for disseminating information and warnings at the local level.

222 International partners are providing support to the country to upgrade and modernize the hydro-met services in order to strengthen flood forecasting and early warning capacities. International cooperation is increasing for water-resources management in general, and basin-wide flood forecasting and warning in particular, after the devastating flood of 2000.

223 The World Bank is supporting Mozambique in designing, implementing and evaluating the dissemination of accurate weather forecasts to communities along the Zambezi, Limpopo and Incomati River basins. WMO, in collaboration with USAID/OFDA, is developing a Strategy for Flood Forecasting and Early Warning in the Zambezi Basin, which comprises Botswana, Angola, Namibia, Zambia, Zimbabwe, Tanzania, Malawi and Mozambique. Munich Re Foundation is working in partnership with the Mozambique Flood Warning Project to provide community operated early warning services along the Búzi River. The Mozambique Red Cross Society is implementing a five-year community-based disaster preparedness programme in Inhambane and Zambezia provinces with support from the Danish Red Cross.

5.1.4 United Kingdom

224 The Flood Forecasting Centre (FFC) is a partnership between the Environment Agency and the Met Office, combining meteorology and hydrology expertise into a specialized hydrometeorology service. The centre forecasts all natural forms of flooding - river, surface water, tidal/coastal and groundwater flooding as well as extreme rainfall that may lead to surface water flooding.

225 The FFC provides a flood warning service throughout England and Wales in areas at risk of flooding from rivers or from the sea and from flooding from groundwater in some parts of England. Using the latest technology, it monitors rainfall, river levels and sea conditions 24 hours a day to forecast possible flooding. If flooding is forecast, then warnings are issued using a set of three different warning types, namely flood alert, flood warning and severe flood warning, using changing symbols.

Figure 15 — Symbols for different flood warning types in the UK

226 In the UK, the dissemination of flood warnings is moving or has moved to become a service whereby those potentially at risk from river flooding can pre-register to receive warnings by phone from an automatic system. Warnings and updates about current conditions are also carried by local radio stations. In addition, internet sites have pages showing which locations have flood warnings in place and communicate the severity of these warnings. A three-day flood forecast for England and Wales is now available on the web, with daily updates. This forecast shows where there is a risk of flooding, county by county, over the next three days.

5.1.5 United States

227 In the US, the National Weather Service (**NWS**) issues flood watches as well as warnings of large-scale, gradual river flooding in order to protect life and property. It also provides basic hydrologic forecast information to promote environmental and economic well-being. Watches are issued when flooding is possible or is expected within the ensuing 12–48 hours, and warnings are issued when flooding over a large area or river flooding is imminent or occurring. Both can be issued on a county-by-county basis or for specific rivers or points along a river. When rapid flooding from heavy rain or a dam failure is expected, flash flood watches and warnings are issued.

228 The Office of Hydrologic Development supports the NWS hydrologic mission by designing, developing, testing, and implementing a physically-based hydrologic forecasting system – the NWSRFS. Thirteen River Forecast Centers (**RFCs**) develop hydrologic forecasts for the U.S. The RFCs use the NWSRFS to make short-term forecasts (a day to a week in advance) of river flows and floods and give long-term, probabilistic river outlooks (a week to months in advance) to support water supply management and flood mitigation.

229 Flood Statements are issued by the NWS to inform the public of flooding along major streams where there is no serious threat to life or property. These statements may also follow a flood warning in order to provide updated information.

230 In the USA and Canada, dissemination of flood warnings is covered by Specific Area Message Encoding (**SAME**) code FLW, which is used in the US Emergency Alert System and NOAA Weatheradio network and in Canada's Weatheradio Canada network.

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ANNEX I : ABBREVIATIONS

ADPC	Asian Disaster Preparedness Centre
ALERT	Automated Local Evaluation in Real Time
APFM	Associated Programme on Flood Management
ARAs	Regional Water Administrations (Mozambique)
AVR	Automatic Voltage Regulators
AWS	Automatic Weather Stations
BBC	British Broadcasting Corporation
BDM	Bangladesh Disaster Management Bureau
BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board
CB	Cell Broadcasting
CBDRM	Community-Based Disaster Risk Management
CEOS	Committee on Earth Observation Satellites
CHPS	Community Hydrologic Prediction System
CPD	Continuing Professional Development
CRED	Centre for Research on the Epidemiology of Disasters
DAE	Department of Agriculture Extension (Bangladesh)
DEM	Digital Elevation Model
DMB	Disaster Management Bureau (Bangladesh)
DNA	National Directorate of Water (Mozambique)
DSF	Decision Support Framework
EQPF	Ensemble Quantitative Precipitation Forecasts
FAR	False Alarm Rate
FFC	Flood Forecasting Centre
FFWS	Flood Forecasting and Warning System
FWS	Flood Warning System
GCM	General Circulation Model
GIS	Geographical Information Systems

GM	General Model
GUI	Graphic User Interface
GWP	Global Water Partnership
HDTS	Hydrometric Data Transmission Systems
HF	High Frequency
HOMS	Hydrological Operational Multipurpose System
HR	Hit Rate
HRU	Hydrological Response Unit
HYRAD	Hydrological Radar System (United Kingdom)
IFLOWS	Integrated Flood Observing and Warning System
IFM	Integrated Flood Management
INAM	National Institute of Meteorology (Mozambique)
INGC	National Disaster Management Institute (Mozambique)
IPCC	Intergovernmental Panel on Climate Change
IR	Infra-Red
IT	Information Technology
ITCZ	Inter-Tropical Convergence Zone
IVR	Instant Voice Response
IWRM	Integrated Water Resources Management
LAM	Local Area Model
LARC	Limited Automatic Remote Collection
LFWS	Local Flood Warning System
LIDAR	Light Detection And Ranging
MAE	Mean Absolute Error
NASA	National Aeronautics and Space Administration (United States)
NEXRAD	Next Generation Radar (United States)
NGOs	Non-Government Organizations
NHSs	National Hydrologic Services
NMHSs	National Meteorological and Hydrological Services
NMSs	National Meteorological Services
NOAA	National Oceanic And Atmospheric Administration (United States)
NVQs	National Vocational Qualifications
NWP	Numerical Weather Prediction
OFDA	Office of U.S. Foreign Disaster Assistance
PoD	Probability of Detection
QPFs	Quantitative Precipitation Forecasts
RFCs	River Forecast Centres
RMS	Root Mean Square Error
SADC	Southern Africa Development Community
SAME	Specific Area Message Encoding
SMD	Soil Moisture Deficit
SOD	Standing Orders for Disaster
TBRs	Tipping Bucket Rain gauges
TOPKAPI	Topographic Kinematic Approximation
TRMM	Tropical Rainfall Measuring Mission
TV	Television
UHF	Ultra High Frequency
UNESCO	United Nations Educational, Scientific and Cultural Organization

UPS Uninterruptible Power Supply System
USAID United States Agency for International Development
VHF Very High Frequency
VSAT Very Small Aperture Terminal
WMO World Meteorological Organization

ANNEX II: TERMINOLOGY

Flood risk land-zone classification

Undeveloped land: *This may be in the upper reaches of catchments (hill pasture, forest) or the lowest parts (flood plain, marsh), where impacts of flooding are low.* However, upland areas frequently form flood generation areas, so effective and adequate monitoring is required.

Agricultural land: *Impacts can be variable, depending on the type of agriculture.* Main beneficiaries would be community sites within major flood plains. Impacts on arable land may be high, but little can be achieved by flood warning, except helping implement control measures to protect irrigation systems. In pastoral areas, flood warning allows time for livestock to be moved to safer areas.

Low-density urban areas: *These comprise scattered villages and small towns within a specific sub-catchment or river reach.* Site-specific flood warnings are uneconomical and of limited use, since levels of risk and impact may vary from site to site.

Urban centres and key infrastructure: *For a number of historical reasons, many major cities have grown up adjacent to river sand in flood plain areas and now have to be provided with flood defences.* The presence of highly valuable property and key infrastructure requires that flood defences be supported by targeted flood warnings in order to mobilize flood management actions.

For more information, please contact:

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