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INTERCOMPARISON OF FLOOD FORECASTING MODELS

Decision-Support for the Selection of Flood Forecasting Models

In support of the WMO Flood Forecasting Initiative

December 2013

Preface

The WMO Flood Forecasting Initiative (WMO-FFI) was established in 2003 through Resolution 21 (Cg-XV). It has an objective to *“Improve the capacity of meteorological and hydrological services to jointly deliver timely and more accurate products and services required in flood forecasting and warning and in collaborating with disaster managers, active in flood emergency preparedness and response”*. An important element in the WMO-FFI is the provision of assistance in choosing the flood forecasting models that are best suited for the objective of the forecast, the hydrological situation, availability of hydrological observations and the professional capacity of the institution that is mandated to issue flood forecasts (NMHSs).

The guidance provided in this document aims to assist the decision-making process in the selection of appropriate flood forecasting models. The method for realizing this aim has been developed on the basis of two expert meetings and extensive discussions with their participants who represented very different environmental and institutional settings.

Acknowledgement

Gratitude is expressed to the participants of both the Expert Meetings held in 2011 and 2013 who contributed actively to the development of the methodology described in this document. Special thanks are extended to the Secretariat of the International Hydrological Programme of UNESCO and the Hydrology and Water Resources Programme of WMO at the Federal Institute of Hydrology in Koblenz, Germany that hosted both Expert Meetings. The abstract of the presentations of the contributors are provided in Annex 1; and the names of participants of both expert meetings are listed in Annex 2 to this document.

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1. Background and scope

The National Meteorological and Hydrological Services (NMHSs) are tasked to protect human life and reduce economic losses by issuing timely and accurate flood forecasts. A forecast can be used by civil authorities to evacuate areas at risk from flooding and to take other precautions to protect life and property. Additionally, forecast can provide the basis for preparing critical infrastructure in order to minimize damages. Forecasts may also be used to inform operators of reservoirs in an effort to mitigate effects of floods downstream of the reservoirs. Flood forecasting is therefore an important service provided by NMHSs.

The transformation of precipitation into channel flow is a highly complex physical process. A common practice is to use a hydrological model to represent mathematically watershed processes. Many different hydrological models have been produced by government agencies, universities, and private companies. They offer a wide range of process simulation options, differing levels of complexity and data requirements, and various degrees of technical support and training. Their application also depends on the forecasting objective, geographical and environmental factors, as well as institutional capabilities. Therefore, the selection of the "best choice" flood forecasting model needs to be based on a systematic approach taking all the factors into consideration.

WMO has initiated various programmes and projects with the aim of supporting NMHSs in their efforts to improve forecasting and forecasting-based services. The overarching programmatic framework in this regard is the WMO Flood Forecasting Initiative (FFI). A key reference for the understanding of flood forecasting and derived services is the "Manual on Flood Forecasting and Warning" (WMO No. 1072, 2011). This manual provides a comprehensive documentation of the main aspects of flood forecasting. It addresses monitoring networks, data management, and hydrological simulation models. Applications, training needs, and implications of flood forecasting are related to the provision of reliable services.

In response to a recommendation made during a workshop on the Strategy and Action Plan of the WMO Flood Forecasting Initiative, held in Geneva in December 2009, activities were undertaken to organize a workshop on the intercomparison of flood forecasting models with the aim to provide decision support for selecting adequate flood forecasting models in hydrological services. During this workshop which was held from September 14 to 16, 2011, 29 international experts from operational services gathered at the Federal Institute of Hydrology in Koblenz, Germany. Eighteen operational flood forecasting systems and models were presented. The aim of the workshop was to discuss operational models and related issues and to initiate a process for providing support in the selection of appropriate methods, models, and settings for specific flood forecasting purposes.

During the workshop, a task team consisting of twelve experts was formed, which are highlighted in yellow in Annex 2. This team was mandated to further develop a "Decision-Support Tool for the Selection of Flood Forecasting Models" aiming to support hydrological services in the selection of appropriate flood forecasting models under a range of different conditions for their applications.

The guidance materials discussed in this report are the results of the work of the task team that met from July 8 to 10, 2013 in Koblenz, Germany. The material is targeted for professionals who are tasked to select a flood forecasting model that is best suited under a range of hydrometeorological and institutional conditions. The target group for this guide are professionals who may not be specialists in flood forecasting but have a basic understanding of hydrology.

1.1. Application purposes for model systems

Hydrological flood forecasting models are used in many types of watersheds. In general all watersheds share some characteristics that include watershed boundaries, surface runoff, and river channels. However, other characteristics may require special consideration when a model or modelling system is selected.

Characteristics that differentiate river systems are:

- Short rivers with flashy runoff response (usually in high relief terrain)
- Large rivers with braided main channel
- Downstream of medium-size and large rivers (large lateral inflow at a point) junctions
- River systems influenced by the operation of dams and reservoirs
- River systems with significant storage in lakes
- River systems with significant upstream regulated inter-basin diversions
- Braided river system in flood plains
- Seasonal river system (as a result of seasonal climatic conditions or pronounced water use (reservoirs, groundwater pumping, water abstractions) semi-arid and arid area, groundwater pumping area)
- Basins with snow peaks

The selection of models or a modelling system should be guided by the requirements for flood forecasting, such as the need to have forecasts issued for multiple locations. This example could be for river basins with multiple forecast locations in different tributaries or sections of the main stem of a river and in basins with large differences in the catchment characteristics. A modelling system designed to support such a need might well include various specialized models.

The purposes of flood forecasting mainly include:

- Protection of lives and properties,
- Flood risk management,
- Optimisation of flood preparedness and flood response measures and
- Optimisation of the operation of water infrastructure such as reservoirs, diversions etc.

1.2. Forecasting situations which are not covered by the guidance material

The forecasting situations listed below require the use of highly specialized models that cannot be easily classified and described. In most cases feasible solutions for such problems are individual and cannot be evaluated with the methodology presented in this material.

The forecasting situations to be excluded are the following:

- Flash floods,
- Urban flash floods,
- Coastal and tidal floods,
- Coastal inundations, e.g. caused by storm surges,
- Ice jams and
- Outburst floods from glacier lakes, dam-break or flooding as a result of dyke failures

1.3. Uncertainties:

Measurements and investigations show that the natural variability of hydrological and meteorological inputs to water resources systems and a lack of perfect knowledge and understanding of all the physical processes occurring in catchments are causes of uncertainty in hydrological forecasts. The Thirteenth Session of the Commission for Hydrology prepared a *Statement on the scientific basis for, and limitations of, river discharge and stage forecasting*, to help further the understanding of such uncertainties.

One possible approach to help reduce forecast uncertainty is to include an appropriate updating procedure in flood forecasting models. Updating procedures are designed to minimise the uncertainty of the simulated flood hydrograph by feeding back into the modelling system the river flow up to the time of origin of the forecast. If these flow values are available in real time then it is widely accepted that updating procedures should be based upon a real time forecast model to improve its accuracy and lead time. There are many ways in which recently observed river flows can be used to update a forecast, and various updating procedures are available (WMO, 2011).

Updating procedures are easily applied to rainfall runoff models of any type and to simple-mass-balance routing models. Applying them to complex hydrodynamic routing models on river sections where river water level data are available, requires expert help from a specialist in that field.

2. Fundamental requirements for the application of flood forecasting models

The implementation of a flood forecasting system requires both human and computing resources. Sufficient resources must be in place to support not only the development of the system but to operate it and maintain it through time. If resources are not available to a particular organisation, they may be sourced fully or partly from external providers. Thus, flood forecasting can be constrained by the institutional capability, the availability and types of data and their representativeness and quality.

Table 1 describes some of the most important requirements to support a flood forecasting service. A brief description of each requirement is given in column 1 and an indication of whether the requirement is mandatory or desirable is mentioned in column 2. An initial suggestion on how the requirement could be met is provided in column 3. More details on the general requirements for implementing and operating a flood forecasting system and service are described in section 2.3 of the Manual of Flood Forecasting and Warning (WMO, 2011).

Table 1: Organisational, computational and data resources required to support a flood forecasting service

Description	**Mandatory / Desirable**	**How to meet the requirement**
Organisational capability		
Ability to configure and calibrate a model		
Hydrologist(s) who understand flood processes Staff who have experience working with numerical software	Mandatory	Recruit suitable staff or train existing staff, can also seek external support
Ability to run a flood model and use the results		
Staff that can be trained to: - review the observations and forecasts that are input to the forecast model - run the models - interpret the output in the context of known flood effects - prepare Outlooks or Warning products that link with risk maps and information required by civil protection authorities (responsible for protective actions)	Mandatory	Recruit or train staff
Computer resources		
Computer to store data, run models and view output		
Computer hardware is required that can host the software that the flood models run on. The hardware available may range from a stand-alone PC to a network	Mandatory	Simple flood forecasting systems can run on a stand-alone computer. This is a minimum requirement.
Network connections		
Access to data feeds required as input to Flood Forecasting Model Ability to communicate forecasts	Desirable	If access to an internet connection is not available then data collection and forecast communication relies on telephones.
Support for computer and networks		
IT staff that can install software and support hardware Staff that can fix these when they stop working		
Data availability	General notes: Stream water level and flow information is a fundamental requirement for flood models. Rainfall data measured on the ground is highly desirable, rainfall estimates and forecasts can be sourced from various meteorological products (e.g. National Weather Service, Global Numerical Weather Forecast)	
Data management system		
A pre-requisite of a flood forecasting system is a functional data management system. Typically this will be a database able to store time series information and the required descriptive information (e.g. station information).	Mandatory	
Manual observations of streamflow and rainfall		
Stream level information can be manually observed at locations where gauge boards are installed. Rainfall depth can be observed using a manually read rain gauge. Manual observations require a communication method (e.g. telephone) and a method of entering the data into the flood modelling system (e.g. spreadsheet file).	Mandatory (either manual or automated or a combination of both)	
Automated data collection network		
Automated data collection is desirable and acts as the backbone of most flood forecasting systems. Compared to human observers, instruments tend to be more reliable (less subject to human error or observer availability) and can provide more frequent, accurate and timely data. Automated instruments, loggers and communication links (telemetry) are more expensive to install, maintain and are subjected to vandalism and theft.	Mandatory (either manual or automated or a combination of both)	Observation data are often sourced from other organizations, commonly agencies responsible for water resource management. Rainfall estimates and forecasts can be sourced from the National Meteorological Office and from globally available Numerical Weather Forecast (NWP) products.

2.1. *Costs of flood forecast service*

The investment in a flood forecasting system includes the initial cost of setting up the system, but by far the largest cost is its ongoing maintenance. This includes: staff wages; data provision; investment in the model including updates; adaptation of hardware; and professional training. Operational costs also include the acquiring of observations to calibrate and feed the model, obtaining tailored Numerical Weather Prediction (NWP) products (e.g. QPF, pQPF, etc.), and obtaining quantitative precipitation estimates (QPE) based on *in situ*, satellite and radar data.

2.2. *Minimum communication requirements*

To ensure the effectiveness of flood forecasting services, it is necessary to communicate the following basic information for the area of interest based on the output of the forecasting model:

- Quantitative gauge heights in relation to warning and alert levels (that needs to be previously established),
- Discharges (based on rating curves),
- Travel time of flood wave and magnitude ,
- Shape of the flood wave (peak or extended),
- Duration of flood situation,
- Recurrence period of the forecast and
- Uncertainty of the forecast.

3. Current Status of Flood Forecasting Models

3.1. Introduction

Comparing Hydrological Flood Forecasting Models (HFFMs) is not a new idea (see for example WMO (1986, 1987, and 1992)). The traditional approach is to select a gallery of models for comparison and a watershed where the models can be run. A common data set is assembled including meteorological data, observations of flow and stage, soil characteristics, and all other data that might be used to parameterize the models. Each model is then configured for the watershed using the assembled data. Performance metrics are defined and subsequently calculated for each model in the intercomparison. This process may be repeated for a variety of different watersheds in various climates or regions of the world representing different hydrometeorological conditions. The general idea is to assess model performance, which could lead to a modeller selecting the single, most appropriate model for a particular set of hydrometeorological and institutional conditions.

In this guideline material, an approach is proposed to support efficient and effective model selection, recognizing that more than one HFFM may perform sufficiently to achieve the goals of a NMHS. Therefore, the principal goal of this report is to facilitate the selection of a most suitable type of HFFM.

Annex 1 of this document contains some information n models and modelling systems sometimes with a summary of the characteristics of watersheds (hydrometeorological conditions) where the model or system performed well, from the modeller's perspective. All the models discussed are operational models. On this basis and from discussion at the expert meetings, a multiple-criteria based selection tool is presented in this guidance material.

The descriptions in the selection tool aim to assist hydrological services in making the appropriate selection for specific applications under a range of controlling factors such as data requirements, the level of professional expertise in a specific service, and other factors as described above in Table 1.

3.2. Flood Forecasting Models, Hydrological model type

Figure 1 provides an overview of model structures and various types of predictive models which are in principle applicable for flood forecasting.

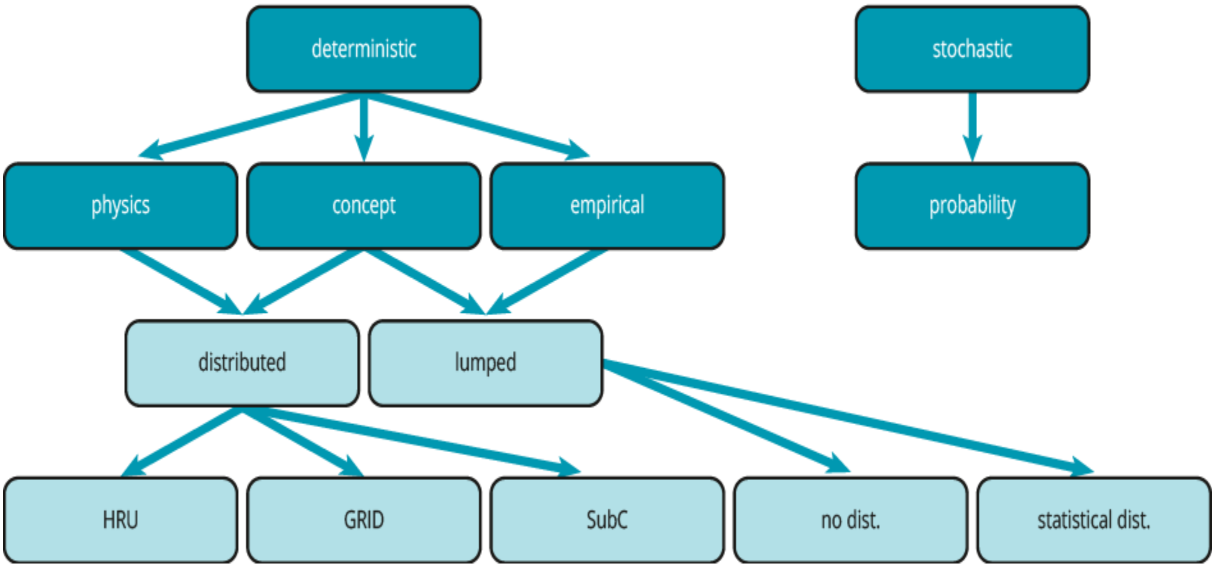


Figure 1: Model Structures and types - classification

3.3. Model resolution

Each model is used and developed for a particular spatial and temporal resolution that depends on a wide range of factors. The temporal resolution depends on the frequency of input data and data assimilation as well as the forecast purpose. The spatial resolution depends on the model`s ability to take advantage of the resolution or granularity of available data (e.g. lumped, semi-distributed, or distributed), the density of the observing network, interpolation possibilities, variability of the flow conditions and the spatial characteristics of the area for which the forecast is issued.

3.4. Examples of operationally used flood forecasting models

Information on each of the flood forecasting models and modelling system is included in Annex 1. A brief summary of the information is included in Table 2. The summary information describes each flood forecasting model from a scientific and engineering perspective, and also the conditions of application.

Table 2: Examples of usage of models under different conditions and data availability status

Country	Name	Model(s)	Main model type	Data requirements	River routing	Probalistic forecasting	Rainfall forecast	Institutional + operational effort	Climatic situation
Philippines	Roy Badila	HBV+MikeFlood/11, HEC-HMS+HEC-RAS, ANUGA	2	3	2	0	0	3	1
UK	Tim Harrison	FEWS + PDM, KW,ISIS,G2G	4	5	2	1	2	5	4
RSA	Brink	Own routing model (based on Mukingum)	5	1	1	0	0	3	2
Mexico	Faustino de Luna Cruz	SAMO	2	3		0	1	3	1
France	Caroline Witwer	Own developments	4	5	2	0	2	5	2,3,4
China	Zhou Li	XinAnjiang	1	2	1	0	1	3	2,4
USA	William Schaffenberg	HEC - HMS	3	4	1	0	1	5	1,2,3,4
Pakistan	Muhammad Shad	FEWS (SAMO, SOBEK)	2	3	2	0	2	4	1
General case studies	Mike Butts	DHI products	4	4	2		2	4	
Italy	Ezio Todini	TOPKAPI	3	3	2	2	2	4	4
Netherlands	Eric Sprookereef	FEWS River Rhine (HBV + SOBEK)	2	5	1	2	1	5	4
Italy	Jutta Thielen	LISFLOOD	3	4		2	1	3	2,3,4
Finnland	Bertel Vehviliainen	WSFS (HBV-like)	2	5	2	2	2	5	4
Bavaria	Affons Vodelbacher	LARSIM + WAVOS + FLUX/FLORIS	3	5	2	2	2	5	3,4
Austria	Hans Wiesenegger	FEWS (FLORIS), COSERO, LARSIM,DHI-MIKE, HBV, HOPI,AspS	4	5	2	2	2	5	3,4
Netherlands	Paolo Reggiäni	REW	2	4	2	0	1	4	1
Germany	Dennis Meißner	WAVOS + Delft FEWS	2	4	2	2	1	4	4

Legends

Main model type

1 Lumped
2 Semi distributed
3 Distributed
4 Combined
5 HD routing only

Data requirements

1 Rainfall/upper river flow
2 plus rainfall + some data
3 plus rainfall hourly,meteo data monthly,DEM,landuse
4 plus rainfall hourly,meteo data
5 plus rainfall hourly,meteo data hourly,DEM,landuse, advanced snow climatic data

River routing

0 No routing
1 Hydrologic routing
2 Hydraulic routing (S-V-Eqs, K-W-Eqs.)

Probalistic forecasting

0 No probalistic forecast
1 Quantile regression etc.
2 Ensembles

Rainfall forecast

0 No rainfall forecast
1 Rainfall forecast
2 RADAR nowcast

Institutional and operational effort

1 Low
2
3 Intermediate
4
5 High

Climatic situation

1 Tropical/megathermal climates
2 Dry(arid and semiarid) climates
3 Mild temperature/mesothermal climates
4 Continentant/microthermal climates
5 polar climates

3.5. Forecast lead time and general implications

The forecasting lead-time requirement depends primarily on the lead-time required by the organization providing the flood warning, and may extend from as little as 1-2 hours to several days ahead. However the lead time requirement is also restricted based on the reliability of the forecast as the time span is extended, which implies that the shorter lead-time forecasts may be used in issuing the actual operational warning, while forecasts at the longer lead-time are used mainly as guidance in moving to a flood alert status, rather than to guide the issuing of a flood warning. For example, Golding (2009) provides for a large-scale flood event in the United Kingdom, given a week's lead-time, the sequence of information driven actions that might arise. A list of lead-times and their corresponding forecasting usage are noted below:

- 3-5 days ahead: Issue 'advisory' or 'period of heightened risk'; engage in awareness raising activities through the media, mobilize support organisations for the vulnerable; initiate
- 'participatory' information sharing by local flood response organisations
- 1-2 days ahead: Issue 'early warning' or 'watch'; activate mitigation measures for flood minimization and protection of critical infrastructure; provide active support to vulnerable groups; move to a consultative engagement with those in the most vulnerable areas
- Hours ahead: Issue 'flood warning'; activate emergency response; evacuate most vulnerable groups if appropriate; provide 'prescriptive' advice to individuals

Although required lead-times differ as a function of the forecast requirement and the considered area, it is convenient to distinguish between two types of forecasting requirements. Flood Warnings are typically issued for lead-times at which emergency response actions need to be taken, while hydrologic outlook statements are used to prepare for mitigating expected flood impacts.

An assessment of the catchment's response time indicates whether sufficient lead-time can be obtained using catchment observations (e.g. river flows, rain gauges) or whether rainfall forecasts are required as inputs.

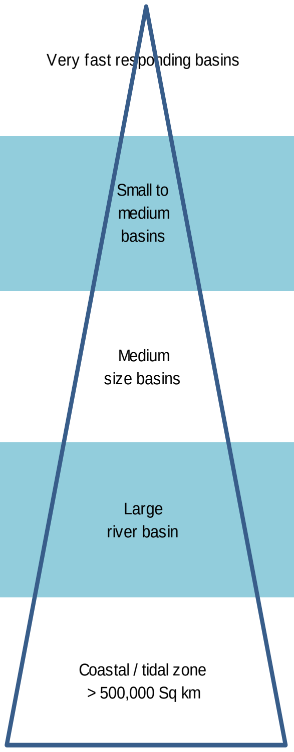
- The ratio between lead-time requirements and catchment response time can be formalised by using a simple classification scheme for flood forecasting, which was originally developed by Lettenmaier and Wood (1993).Considering a single forecasting point in a catchment, the adapted classification scheme compares the desired warning time ($T_{warning}$) to the total response time (T_{total}) at the location for which the forecast is to be provided.

$$T_{total} = T_{river} + T_{catchment} \qquad \text{(equation 1)}$$

- This response time is further subdivided into the hydraulic response time (travel time through main river, T_{river}) and the hydrological response time (which is less than the response time of the catchment, $T_{catchment}$). (Equation 1)
- An additional lead-time (T_{surge}) is also applicable for coastal forecasting situations, although coastal forecasting is outside the scope of the present report. This division is somewhat arbitrary but generally the river channel is considered to be the main river, whilst the hydrological response is the response of sub-catchments before water flows into the main river system.

The situations defined in Table 3 indicates the types of forcing inputs which may be required at each forecasting point in the catchment, and these general categories are illustrated in Figure 2. For example, for Type 1 situations, rainfall forecasts are essential and, if conditioning of outputs is used, this would require an archive of forecast values (perhaps obtained using a hindcasting exercise). For catchments with multiple forecasting points, each point needs to be considered in turn and then the forcing inputs assessed.

Table 3: Links between lead-time requirements and catchment response (adapted from Lettenmaier and Wood (1993))[1]



Type	Catchment	Criterion	Description and key forcing inputs for flood warnings
1	Very fast responding basins	$T_{warning} >> T_{total}$	The desired lead-time is such that the warning or outlook must be issued on the basis of water that has not yet fallen as rain. In this case a rainfall forecast is the only means to provide a timely warning when using a flood forecasting model. Effect of other important factors like basin size is discussed in Table 4.
2	Small to medium basins	$T_{warning} < T_{total}$ or $T_{catchment} >> T_{river}$	The warning or outlook will be issued on the basis of water that is already in the catchment and is mainly determined by the hydrological travel time. Available rainfall forecast and RADAR nowcast also plays a very important role. This may be the case for point I in Figure 2.
3	Medium size basins	$T_{warning} < T_{total}$ & $T_{catchment} \sim T_{river}$	The warning or outlook will be issued on the basis of water that is already in the catchment and river and the response time is determined by the hydrological response time and the hydraulic response time. This may be the case for forecast point IV in Figure 2.
4	Large river basin	$T_{warning} < T_{river}$ or $T_{catchment} << T_{river}$	The warning or outlook will be issued on the basis of water that is already in the main channel; or the hydrological response time is insignificant compared to the hydraulic response time. This may be the case for the forecast point VII in Figure 2, assuming catchments E and F have only minor contributions.
5	Coastal / tidal zone > 500,000 Sq km	$T_{warning} >> T_{surge}$	The desired lead-time is such that the warning or outlook may be issued on the basis of wind conditions that have not yet occurred. In this case wind and pressure forecasts are necessary for a timely warning.

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[1] Note that the sizes of the basin (small, medium, large) are indicative and do not follow WMO Technical Regulations Volume III – Hydrology definitions.

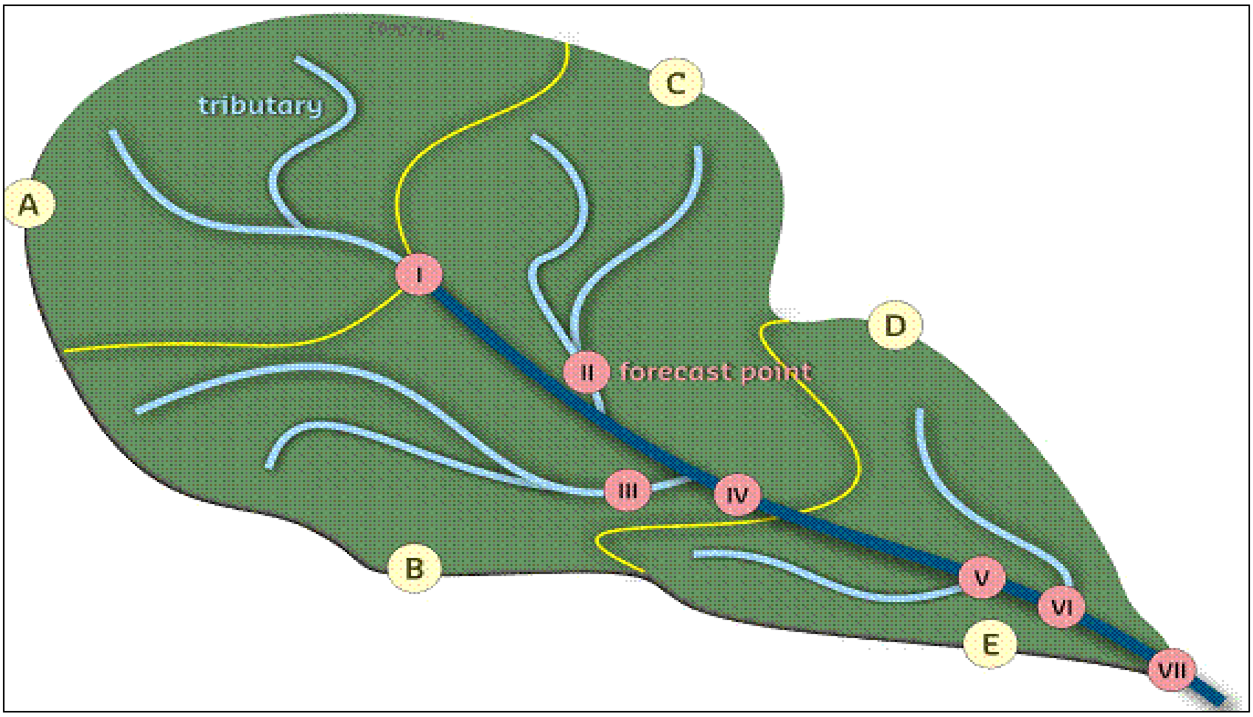

Figure 2: Schematic layout of a catchment, including the main river, tributaries and catchments (adapted from Lettenmaier and Wood (1993)).

In estimating the actual time available, an allowance also needs to be made for the various time delays in the decision-making and warning process. These can include the following, UK Environmental Agency (2002):

- The time taken for information to be received by telemetry
- The time taken for a routine real-time model run
- The time taken for flood forecasting and warning staff to decide to act upon a forecast of levels exceeding a Flood Warning trigger level (e.g. whilst performing 'what if' runs)
- The time taken for all properties to be warned (e.g. via an automated dialling system).

4. Guidance for the Selection of the Model Type for Flood Forecasting

This chapter presents two tools for selecting models. The selection criteria are listed below in section 4.1. The second part of the chapter describes the tools in detail.

4.1. Model Selection Criteria

- **Hydroclimatic condition**
  - Tropical/megathermal climates
  - Dry (arid and semi-arid) climates
  - Mild Temperate/mesothermal climates
  - Continental/microthermal climate
  - Polar climates
- **Catchment characteristics**
  - Terrain
  - Size
  - Land use
  - River network
  - Diversions
  - Water abstractions, reservoirs, lakes etc.
- **Forecast purpose**
  - Short term/long term
  - Quantitative forecast/ flood outlook
  - Warning/management
  - Stage/volume
  - Depth/duration
  - Gauge related/ area related
- **Institutional and operational requirements and professional capabilities**
  - Low
  - Low – intermediate
  - Intermediate
  - Intermediate – high
  - High
- **Model type**
  - Lumped
  - Semi-distributed
  - Distributed
  - Combined
  - Routing only
- **Routing**
  - No routing
  - Hydrological routing
  - Hydraulic routing (Saint-Venant’s equations, Kinematic wave equation)
- **Data availability**
  - Rainfall type and characteristics
  - Gauge information (stage/discharge)
  - Wetness conditions/soil moisture
  - Topography, land use, soils
- **Weather forecast availability**
  - Radar rainfall nowcast
  - Rainfall forecast (QPF, pQPF)
  - (Resolution of the available weather forecast products also influence the selection of the hydrological model)

4.2. Explanation of the decision matrix and the decision tree

The proposed methodology to select the best suited model consists of a two-step approach. It contains a decision aiding matrix and a decision tree.

In the decision matrix provided in Table 4, nine questions related to flood characteristics and processes help stakeholders to select an appropriate general model type for their specific forecasting context. Once a suitable model type is identified, the second step is to use the decision tree which guides in finalizing tailored forecasting model configurations that best suit the forecasting purpose under prevailing conditions, as described in section 4.1.

4.3. Guide to the use of the decision matrix/decision tree

Decision matrix

The “decision matrix” indicates possible choices of models and their configuration/modules. Since it is not a deterministic approach, answers to questions might lead to different outcomes. Thus, to reach a final solution, a comprehensive, iterative re-evaluation of boundary conditions and the feasibility of the solutions need to be done. Reference to explanatory remarks while working with the matrix could be helpful. The decision matrix holds nine questions with multiple, possible answers. Each answer yields a direct consequence for the selection of a forecasting model. The first two questions help selecting the basic model type that is appropriate for the given situation and watershed. The next three questions support the choice of model features to take into account key processes. Questions 6 and 7 are targeted to find the right rainfall input type and resolution. Up to this point the questions provide guidance towards a first-pass model selection based on basin and hydrometeorological characteristics as well as the required lead time. The final two questions take into account constraints in the development and application of the chosen model. It is important to note that if questions 8 and 9 impact on the model choice, model selection should be revised by improving related data issues and/or service capabilities.

Table 4: Decision matrix

Model type	**Question 1**	**Catchment size?**						
			small(headwater)		medium		large	
	Catchment model		lumped		semi-distributed		semi-distributed / distributed	
	Routing		mostly not needed		hydraulic/hydrologic		hydraulic, hydrologic, gauge to gauge correlation	
	Question 2	**Catchment relief?[1]**						
			flat/plain		moderate/hilly		pronounced/mountainous	
		Catchment area	small	large	small	large	small	large
	Catchment model		lumped	semi-distributed	semi-distributed		lumped	semi-distributed / distributed
Model features	Question 3	Does soil wetness affect flood generation? [2]						
			no		to some extent		yes	
	Soil water budegt feature required		not needed		recommended		needed	
	Question 4	Is snowmelt important for flood generation? [3]						
			no		to some extent		yes	
	Snow module		not needed		recommended		needed	
	Question 5	Is river regulation (reservoirs/lakes/diversions) affecting floods?[4]						
			no		to some extent		yes	
	Storage module		not needed		recommended		needed	
Data requirements	Question 6	What is the predominant flood causing rainfall?[5]						
			seasonal		frontal/advective		convective	
	Recommeded data resolution		daily		daily/hourly		hourly/sub-hour	
	Question 7	What is the required lead time?[6]						
			short		medium		long	
		Catchment area	small	large	small	large	small	large
	Required rainfall data		rainfall forecast and radar nowcast	observed rainfall	rainfall forecast and radar nowcast (recommended)	rainfall forecast and observed rainfall	rainfall nowcast and/or forecast from NWPs is required	rainfall forecast and observed rainfall
Constraints	Question 8	Are distributed/gridded data available for landuse and climate? [7]						
			no		yes			
	Catchment model		lumped model is only option		semi-distributed/distributed model is feasible			
	Question 9	What is the level of capability of the service?[8]						
			low		intermediate		high	
			only simple tools feasible(correlations etc)		run lumped/black box simple models or semi-distributed (External experts can be hired for implementation of models)		all options available	

Legends

1	Lumped: Only basic data are required (mean slope, area, etc), Semi-distributed: DEM,soil type,landuse data required, and Distributed: Usually detailed data are used and then aggregated.
2	Climate data are needed, evapotranspiration estimates needed, soil water measurements are indicated for calibration.
3	Temperature data required, preferably radiation and wind. The question is irrelevant for tropical zones.
4	Controlled river regulation requires operation rules. Other relevant factors depending on the area should be taken into consideration eg. Snowmelt, ice jams, reservoir releases,etc
5	Raingauge density is often insufficient for small basins/convective rainfall.
6	Concentration times need to be considered. Indications for lead times: short lead time is in the range of half or less of the concentration time. Medium is in the range of the concentration time. Long is a multiple of the concentration time. In general the terms used as short, medium, long leadtimes and small, large areas are indicative and donot follow WMO technical regulations (Hydrology) terminologies.
7	Disaggregartion of data (especially rainfall) is often a source of error.
8	The capability of a service is depending on quality and quantity of available staff and resources (computers, etc).

4.4. Decision tree

The “decision tree”, as shown in Figure 3, consists of a number of questions which are sequentially evaluated. Depending on the answer, a certain path can be followed; and, consequently, specific selections of model components and required data can be made.

Basically, the different elements of the decision tree are:

a. Question,
b. Model component,
c. Data requirement.

The approach neglects the existing data situation of a potential forecaster, but based on the governing flood-causing processes, it helps to identify the required data and modelling components. Therefore, as a result of following the decision tree, it may be found that additional data collection is necessary before a model may be implemented. Based on the feasibility of the modelling, other model types might have to be chosen according to the data situation and forecast objective.

The answers to the series of questions lead to an array of modelling components, each of which is associated with certain data requirements. The first three questions of the decision tree determine whether a rainfall runoff model is needed or a simple flood routing based approach is suitable for the specific forecast situation. The six questions related to the rainfall runoff model helps in selecting appropriate modules which take into consideration the dominant hydrological processes in the considered catchment. The overall decision tree guides the user with regard to the data requirements for the different modules.

Example: A possible outcome, as indicated by the dotted line in the figure, could be: no routing model is needed and rainfall-runoff processes are accounted for with a distributed model, which in turn needs to hold a soil-water component for estimating the antecedent wetness conditions. Rainfall data have to be provided on an hourly basis, since flood-causing rainfall is dominated by convection. As a consequence of the above selected models and since the forecast horizon should be extended, the forecaster would need data for the DEM, land use, soil, climate, and rainfall from *in situ* ground, satellite and RADAR. The decision tree allows for browsing through a set of specific conditions and leads to a choice of model components that are appropriate for the forecast objectives of single users.

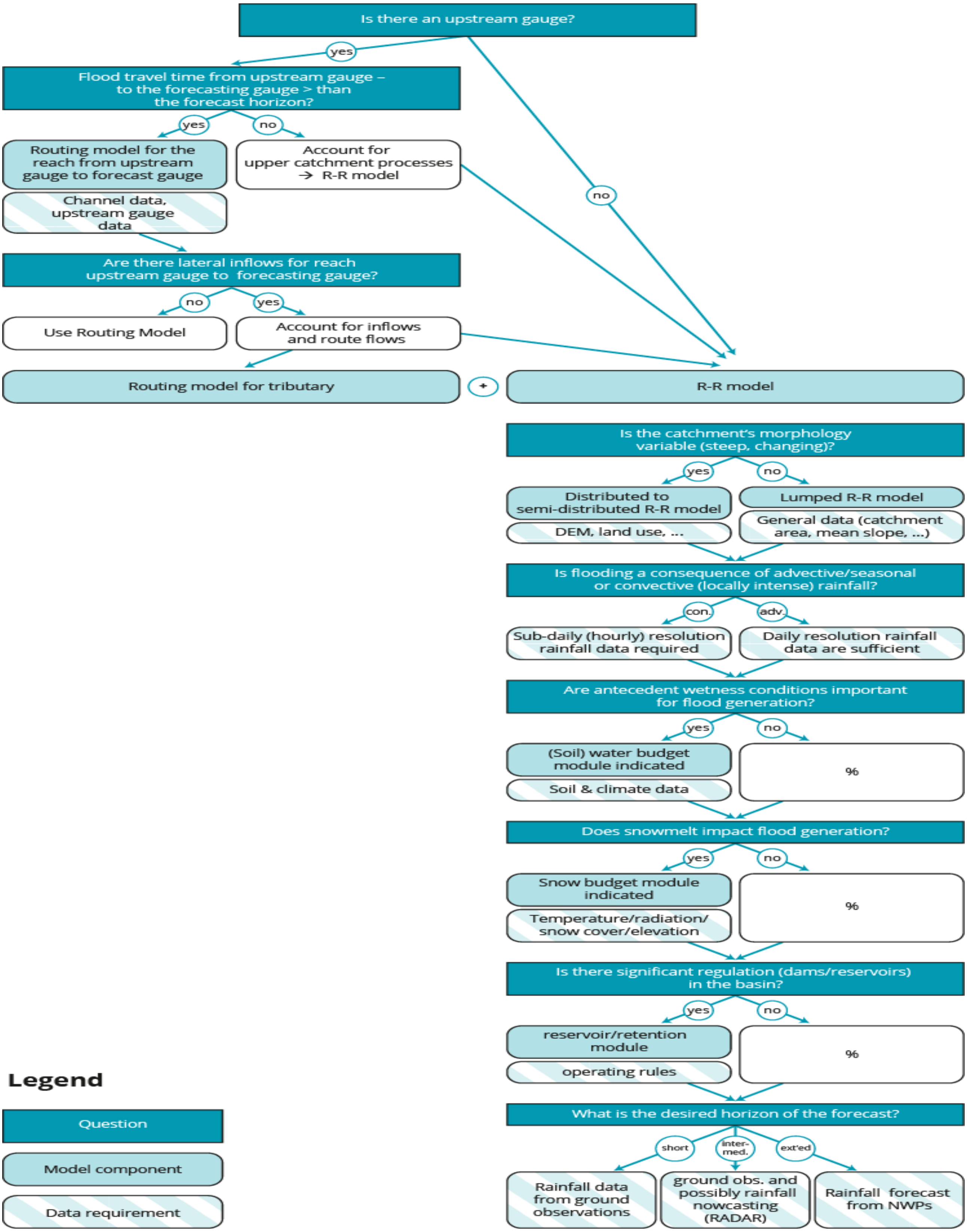

Figure 3: Flow chart showing decision tree

5. Example use of the decision matrix

The four examples given below illustrate how the decision matrix, as listed in Table 4, can be used to guide the selection of an appropriate HFFM. However it has to be kept in mind that the decision matrix only helps in identifying the necessary characteristics of the HFFM and more than one model may meet the identified requirements.

5.1. Example 1

I A watershed is located in Central Asia and has a drainage area of 47,000 km^2. The terrain is mountainous with steep slopes, extensive bare rock with some shallow soils, and sparse vegetation. The elevation ranges from 1000 m up to 4000 m. The main river draining the watershed is approximately 500 km long. Half of the runoff in the watershed is due to snow that accumulates in the winter and melts in the spring. Multiple villages are located along the river and would benefit from reliable flood forecasts. The watershed is classified as large* which points to a semi-distributed or distributed modelling approach in order to represent variation in precipitation and temperature. A number of river reaches will be necessary to route the flood wave down the main river between the multiple villages. (*The classifications of basin sizes are not according to WMO Technical Regulations Volume III - Hydrology)

II The watershed is classified as "pronounced" and further points to a semi-distributed or distributed modelling approach required. This will be especially important for representing the strong temperature gradients that exist in mountainous terrain, which have a strong influence on snow melt.

III The shallow soils will have very little moisture storage capacity. Any storage capacity will be quickly saturated when the long spring melt season begins. There is likely to be little dependence on antecedent soil moisture conditions. Therefore, a detailed continuous soil moisture model is probably not necessary.

IV The climate includes both snow and rain and therefore snow modelling will be a central focus.

V There are no major reservoirs or upstream inter-basin diversions. Therefore no storage module is needed for upstream reservoirs.

VI The advective rainfall is the primary cause of flood events. However, due to the fact that the catchment may react fast, also as a consequence of intensive snowmelt, it is recommended to set up the flood forecasting model on an hourly time step.

VII The required lead time for the forecast purpose is medium. That is why it is recommended to use rainfall nowcast based on radar technology. If such technology is not available, it may be sufficient to use real time information from precipitation gauges. In the latter case it is necessary to carefully check whether such information allows for producing forecast with the lead time required.

VIII Gridded data are available. Therefore, and based on the fact that the catchment has a pronounced relief and drainage system, it is highly recommended to use a semi-distributed or distributed model.

IX The capacity of the service is considered high, and that implies well trained staff and sufficient resources. As a consequence, it seems promising to use a complex semi-distributed or distributed model with real time data.

5.2. Example 2

A watershed is located on a small island in the tropics and has a drainage area of 10 km^2 with an elevation range from 5 m up to 20 m. The watershed is mostly covered with forest with some small plots cleared for agriculture. Runoff is mostly caused by thunderstorms that may occur daily, but at other times there may be several weeks between storms. Large cyclone storms also pass over the island. There is a village at the outlet of the watershed that would benefit from reliable flood forecasts.

I The watershed is classified as "small", which means that a lumped hydrological model is likely to be sufficient. River routing may not be necessary.

II The watershed is classified as "flat", which further points to the possibility that a lumped approach may provide good results.

III The watershed is subject to storms that may arrive irregularly. Evapotranspiration will be strong between storms and will result in drying of the soil. There is likely to be a strong dependence on antecedent soil moisture, indicating a need for a continuous soil moisture model.

IV Snowfall never occurs; a snow model is not needed.

V River regulation does not affect flood generation; a reservoir module is not required.

VI The island often receives precipitation from intense thunderstorms which are short in duration but often produce high rainfall rates, which points to a short time interval. Additionally, the small watershed size further points to a short time interval. Hourly precipitation will be a minimum requirement and sub-hourly precipitation may be necessary.

VII The watershed is very small with a quick response time. This suggests a “short” forecasting horizon. A good rain gauge network may not be sufficient. A good rainfall forecast facility is required.

VIII Neither gridded nor detailed data are available. A lumped model is the only viable option.

IX The solution for this case seems to be a simple lumped model or an empirical approach. Thus staff trained to deal with such data and models would be highly recommended.

5.3. Example 3

A watershed is in the middle latitudes and has a drainage area of 2,000 km^2 and a water storage facility in the basin. The terrain is composed of low hills with deep soils that support productive agriculture. Elevation ranges from 25 m up to 200 m and snow is rare. The climate is generally a Mediterranean-type with a dry season approximately half of the year followed by a wet season when large-scale storms may arrive on an interval of 3 to 10 days apart. There are three small cities along the river that would benefit from reliable flood forecasts.

I The watershed is classified as “intermediate”, which points to using a number of catchments and some river reaches in order to route the flood wave.

II The terrain is classified as “moderate”, which further points to using a semi-distributed approach. This could be achieved with many small catchments.

III The watershed experiences long and dry summers with no precipitation and hence no floods occur. The winter season includes periods when storms occur in rapid succession and the soil may remain near saturation for several weeks. However, there are also periods of days or weeks between storms when the soil would be drying. Therefore it may be necessary to select a continuous soil moisture model, though it may not be absolutely necessary.

IV The watershed rarely receives snow and therefore a snow modelling component is probably not necessary.

V The watershed is equipped with artificial water storage (reservoir). A storage module is necessary in order to model the flood attenuation in the storages as well as to define adequate flood mitigation options for the operation of the reservoirs.

VI The watershed is primarily affected by advective storms, and this may permit a daily time interval. However, it may still be more appropriate to pursue an hourly time interval to provide improved resolution of the flood wave routing as well in assuring adequate modelling of the sub-catchments as input to the main channel.

VII The watershed has an intermediate response time and is classified as an “intermediate” forecasting horizon. A good rain gauge network is required along with Quantitative Precipitation Forecast (QPF). Alternatively, RADAR rainfall may be used with RADAR- based nowcast for the future precipitation estimate.

VIII Gridded data are partially available. It is therefore possible to also use a semi-distributed or distributed model.

IX The capacity of the service is generally high, therefore the model could be as complex as necessary.

5.4. Example 4: Applying the decision matrix for the Kuban river basin

The watershed of the Kuban River is located on the northern slope of the Caucasian range and has a drainage area of 58,000 km^2. Around 50% of the basin area has mountain relief with harsh terrain and high altitudes reaching 4000 m. Length of the main river is 870 km. The river runoff has mixed origin; the major components are snowmelt waters (35%) and rain waters (45%). Snow pack duration varies from 70 days on the flat terrains and up to 200 days a year in mountains. Summer rainfalls, usually of convective origin, induce rain floods. Glaciers cover a total area in the basin of approximately 204 km^2 (1.5% of the total basin area). The Kuban river basin is densely populated and has developed economical facilities. There are rather highly developed water usage facilities (reservoirs, canals), that influence the runoff regime of the river.

I The watershed area is large. This means that runoff formation processes are variable along the basin area. Such variety should be described using a semi-distributed or distributed model. Also, the large watershed points to the need to use routing model in order to represent flood wave movement along the river reach.

II The basin's relief is mountainous. Mountains cover around half of the basin. The river runoff generation area is primarily located in mountainous sub-catchments. Altitudinal zonation effects makes runoff conditions much more variable along the watershed. This demands for more detailed description of the spatial variability of the runoff formation processes which can be achieved by using semi-distributed or distributed model.

III Antecedent wetness conditions affect flood generation. Water processes in the soil aeration zone affects water regime of the river significantly. Thus, a soil sub-model is needed.

IV Snow melt is the important factor causing floods. Snowpack formation is significant on the watersheds. Melt waters give around 35% to the total river runoff. Thus, incorporating a snow accumulation and ablation sub-model is essential.

V There is water infrastructure in the basin. A number of reservoirs on the main river and its tributaries impact on runoff propagation downstream. It is necessary to take into account such water activities by using a reservoir regulation sub-model.

VI The flood-causing rainfall pattern is mainly convective. The convective rainfall characteristic means that there is a need in hourly or sub-hourly resolution precipitation data. The present rain gauge network in the river basin is quite sparse in mountain areas and provides precipitation measurements twice daily. Only daily (or 12 hour) precipitation resolution is available.

VII Long range forecasts are required. To run the hydrological model in operational mode with several days lead time, meteorological forecast lead time of up to several days is required. The forcing for such forecast is provided by NWP models. Two mesoscale models (COSMO, WRF) are running in the Hydromet Centre of Russia and forcing from two centres (NCEP, UKMO) are received twice daily.

VIII Gridded data are available. A semi-distributed or distributed model is possible.

IX The service capability is high with highly qualified staff. The forecasting centre that will operate the model have on staff scientists and software engineers experienced in distributed modelling. The forecast centre is equipped with personal computers and a main frame computer having high computational capacity, which is used for various purposes like data assimilation, running mesoscale meteorological models and so forth.

According to the answers from the decision matrix, as described in section 4.3, questions 1-5 suggests that the model of choice would be semi-distributed or distributed with soil, snow and reservoir sub-models. Such hydrological models are capable of simulating and forecasting river flow for the river. Staff and computational demands formulated in questions 8-9 are met in the forecast centre. The requirements for precipitation data as per questions 6-7 are affecting the model of choice. NWP models are also available, but the observed rainfall data (time sampling and number of sites) are insufficient for running either a semi-distributed or distributed model (question 6). There is no possibility to optimally use the model of choice as derived from use of the decision matrix. There are two main outcomes from the decision matrix analysis:

I Modernization of the observational network is needed for the basin in order to meet appropriate hydrological model demands. Now a vast project of Roshydromet network modernization is being done on the Kuban river basin – majority of stations are being automated, a number of Doppler radars are being installed.

II Until the network modernization project is complete, less data demanding but also less effective hydrological models can be chosen for operational forecasting in the basin. Hence, a semi-distributed model operating on a daily time step will be used. As soon as the temporal and spatial resolutions of data have been sufficiently increased, a semi-distributed or distributed model should be developed and implemented for operational use.

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Annex 1: Short description of contributions by experts

1. FLOOD FORECASTING and WARNING SYSTEMS of the PHILIPPINES

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SUMMARY:

The Metropolitan Manila has been experiencing recurrent flooding especially in the low lying areas along the Pasig-Marikina River and its tributaries. The Philippine government has been implementing several mitigating measures to arrest the escalating effect of flooding in the area and one of these is the construction of Mangahan Floodway. The floodway was designed to reduce flooding further downstream of Marikina River and Pasig River. Several years after the construction of the floodway, settlers occupied its slopes and embankments making it risky to operate the Rosario Weir located at the mouth of the floodway near the confluence of Marikina River. The Rosario Weir is to be opened whenever the flood level along Marikina River is high to divert flood waters to Laguna Lake for temporary storage.

Knowing this problem, the Philippine government has again embarked on another project which is the flood early warning system along the Mangahan floodway. A telemetered rainfall and water level system was introduced in Pasig-Marikina river system and warning post with audio and siren installed along Magahan floodway. These equipment are controlled at Rosario control station.

The upper Marikina catchment was modelled using the HBV model software. The HBV model was set-up, calibrated and validated using hourly rainfall and water level data, land cover map, meteorological data for evapotranspiration calculation and SRTM derived DEM for catchment extraction. The result of the HBV model simulation is then routed along the upper Marikina River to predict the water level at Sto. Nino water level station which is the basis for the operation of Rosario Weir.

2. Matching models to the forecasting goals: Some illustrative case studies

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The key messages of this presentation, are 1) that the selection of forecasting models must match the available data and the purpose, and that forecasting systems should 2) provide easy-to-understand information for decision-makers and 3) maximise the accuracy and the value of scarce real-time data by always using real-time updating (data assimilation).

In many modern forecasting systems the modelling tools used to generate flood forecasts form part of a more general flood forecasting system. This provides extra flexibility, allowing forecasters to use different types of models, for example simple correlation models or 2D hydrodynamic models within the same framework. It also allows the use of different models for different basins, on multiple computers or a cascade of models from upstream to downstream along a particular catchment. Forecasting systems are about collecting and then providing forecasting information to the right people, at the right time and in manner that is easily understood. For example on-line displays can provide information to different user in different countries. Operators of the Three Gorges Dam, China can generate inflow forecasts exploring different operating strategies through a single tailored user interface.

In the same manner, both forecasting models and forecasting systems need to be adapted to local requirements and conditions. In Bangladesh, a comprehensive forecasting model using both the hydrological and 1D hydrodynamic components of MIKE 11 is used. Hydrodynamic modelling is needed to represent flooding in a complex and looped network, with low slopes and tidal influences. Conditions are challenging as much of the country may be inundated during the monsoon flood season. Satellite imagery or aerial photographs can be used to ensure the reliability of the simulated flood extent from either 1-D or 2D models.

In the Mantaro Basin, Peru, the main requirement is to forecast the natural inflow to the turbines during the coming days and estimate the inflows that can be expected to the various reservoirs during the coming months, .i.e. both short-term and long-term (seasonal) forecasting is required1. This information is then used to decide when to release water from remote reservoirs and to operate the turbines. The rainfall-runoff modelling is carried out by the MIKE 11 NAM model and the water allocation, reservoir operation and channel routing is carried out by MIKE BASIN. This choice of models, together with extended streamflow predictions provides both short-term and long-term forecasts as well as optimisation of the operating strategy.

The Big Cypress Basin is characterised by close interaction between the surface water and groundwater and an artificial drainage network, with limited storage and numerous control structures. The fully integrated hydrological model MIKE SHE is able to properly represent these key features. The MIKE FLOODWATCH forecasting system used not only to generate flood maps but structure operation monitoring and flood alerts based on threshold.

3. A reminder on flood forecasting models

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This contribution stated on six features of: (1) forecast skills for extremes at challenging biomes, (2) flood uncertainty awareness and management, (3) comparison methods like blinding-forecast versus radar-based forecast, (4) scaling techniques for flood forecasting, i.e. spatial disaggregation and time auto-correlation, (5) possible pathways of friendly flood forecasting for communities and (6) an step forward on participatory flood forecasting. Flood extremes in challenging biomes under pressure are common. For instance, floods at large rivers like Amazon attain uncertainty confidence intervals of ca. 100.000 m3/s at rating curves! Otherwise, uncertainty awareness of floods measured at rating curves in Southern Brazil would achieve errors of average cross-sectional velocity by a factor of 50% before and after the occurrence of floods related to El Niño Southern Oscillation (ENSO).

These baseline constraints impose limits on how to compare flood forecasting methods, especially with benchmarks from real-time and radar-based forecast at a distributed modelling. For those reasons, scaling techniques of spatial disaggregating runoff surplus, thereby converted into runoff generation and flood propagation techniques, need further development. Not only because of the nature of rainfall fields, but also due to the dynamics of cold/hot fronts attempted as main responsible of how time correlation techniques for flood prediction must be refined, if feasible. In South America region, well-behaved rainfalls have more predictability in autocorrelation functions related to flood forecast, but they are the exception. Thus new mixed schemes, like friendly flood forecasts linked to radar-based, web- GIS driven and remote sensing techniques, depict promissory layouts for vulnerable communities and settlements. Flood forecasting signboards and real-time flood risk management games are being proposed as an step forward on participatory flood forecasting at municipalities and for riparian population. For the period of 2011-2015, when Brazil will host Olympic Games and World Football Cup, the estimates of investment and operational costs of flood forecasting systems are ca. of US$ 200-250 million/year. Although all forecast models are still not well documented, South American municipalities are acknowledging flood forecasts updated under a distributed modelling. With empirical and conceptual algorithms, a medium skill is needed to operate current models like either MGB (offline basis) or CPTEC/INPE (real time, with high grade of automatization). Special needs are for freeware models used under authorization and new international disaster centers researching floods are under progress. Public-private partnerships are open between national and foreign consortia to propose concrete solutions for efficient flood early warning systems.

4. River Forecasting System (RFS – SPR)

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As part of a program to modernize water resources management in Mexico, since 1996 the National Water Commission from Mexico (Comisión Nacional del Agua, CONAGUA) and the National Weather Service (NWS) from USA have been working together to implement river-forecasting technology here. This cooperative effort involves transferring the capabilities of the NWS River Forecast System (NWSRFS) to Mexico, and developing self-sufficient forecasting skills within CONAGUA.

Through the combined efforts of CONAGUA and NWS, the river forecasting system has been tested and installed on workstation-class computers at CONAGUA facilities in Mexico City and other Regional offices in Mexico. The system uses the existing data collection network in Mexico to provide meteorological and hydrological data inputs, the information has been compiled and analyzed hydrological and meteorological data that have been collected historically for the basin, processed the data for use in forecasting applications, calibrated the hydrologic and hydraulic models used by NWSRFS, and configured and initialized the system for forecasting in 19 basins. As the main office in charge to keep these systems operating in Mexico we have had to face several issues as attrition, insufficient regional training, aging equipment, regional software maintenance, forecast configuration obsolescence, technical trained staff desertion, also we need to incorporate more information to our systems such as data inputs, for instance satellite precipitation processing, radar data integration, update the data collection network and recalibrate the hydrologic and hydraulic models, and change our whole systems (semi distributed models to distributed models) and software (CHPS/FEWS) in order to improve our forecasts and products and reduce the uncertainty the we may able to expand the implementation of new Operating River Forecast System in the rest of Mexican basins in order to help to reduce infrastructure damages and most important as much as we can avoid human life lost. Currently we publish and update daily the forecasts and products at web site: http://www.conagua.gob.mx/spr/

5. Water-Level Forecasting along the major rivers in Germany

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The presentation gives an overview of the administrative competences in Germany related to water-level forecasting ("German forecast jungle"). The different responsibilities of the federal states (in charge of flood forecasting) and national authorities (in charge of traffic related forecasting along the Federal Waterways) originating from the federal system of Germany are explained as well as the aims and tasks of the Federal Institute of Hydrology (BfG). Along the major rivers crossing Germany flood forecasting is organized like a chain composed in flow direction, which means that the upstream forecasting center passes data and forecasts for their area of responsibility to the downstream center(s). Examples for the River Rhine and Elbe are shown.

The large variety of hydrological and hydrodynamic flood forecasting models within Germany are (in most cases) operated in forecasting systems managing in addition the whole pre- and post-processing (especially operational data download, data validation, data preparation for model runs, coupling of models, model updating, publication etc.). For the major rivers in Germany the use of continuously applied hydrological models (in contrast to event based rainfall-runoff models) driven by hydro-meteorological data (measurements + forecasts) whose output is used as boundary conditions for one-dimensional (1D) hydrodynamic models calculating the flood routing along the main rivers is state-of-the-art by now. In the future the 1D-approch might be displaced / supplemented my coupled 1D-2D-approches.

For the River Rhine the BfG uses a combination of the two forecasting systems WAVOS (developed by BfG) and Delft-FEWS (developed by Deltares). Although from a technical point of view the whole forecasting process could be run automatically, BfG decided to define several stages where the forecaster should check the data / model results, as automatic routines accounting for data / model failure are still not as good as manual checks. Due to the philosophy of BfG every forecast which is published should be validated by an expert. In addition BfG publishes as an online quality check for the forecast users a continuous comparison of measured and predicted water levels of the past four days.

Beside the typical station-related forecast more and more federal states started to publish region-related forecast for smaller catchment (~ 200 – 500 km²) with higher uncertainty and short lead times compared to the major rivers. These kind of forecast serve as pre-warnings to the public and are normally based on the results of a hydrological model.

BfG will start a research project for the next three years which aims at improving operational methods for reduction and quantification of (total) forecast uncertainty based on data assimilation and ensemble-techniques on different scales.

As the three most important issues in flood forecasting we identified:

- adequate identification, quantification and communication of the sources and magnitude of forecast uncertainty

- Construction of “optimal balanced” forecasting systems (Forecasting Models are one (important) part of forecasting systems, but one shouldn't neglect the other components (data measurement, pre-processing etc.) and their interaction with the model approaches

- reduction of discrepancies between practical / operational forecast applications and research objectives

Related links:

www.hochwasserzentralen.de

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www.bafg.de/vorhersage

6. Lumped versus physically-based approaches in hydrological modelling: the Representative Elementary Watershed (REW) model

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Watershed modelling is facing new challenges. Whereas in past decades hydrological simulation models were mainly used by operators to simulate the rainfall-runoff behavior or river basins, there is an increasing need to analyze long-term water yield and the impact of land-use and environmental changes on the hydrological response. In this context the use of lumped conceptual models has several limitations. These are mainly attributable to the fact that conceptual models are formulated on the basis of the mass balance only, whereby flux relationships are parameterized by power-law relationships. The corresponding parameter values have no direct physical interpretation, are not observable in the field and can be determined exclusively by calibration on historical data sets.

For this reason lumped-conceptual models have limited applicability in poorly gauged river basins, or in situations where environmental conditions change significantly over short time, as frequently observed in developing countries.

Physically-based models on the other hand use governing equations such as mass, momentum and energy conservation, in which the parameters have physical meaning and can be observed directly in the field. In absence of historical series for model calibration, parameter values can be transferred from adjacent regions with comparable characteristics. A physically-based description of the system also offers the opportunity to exploit advanced and novel data sources such as digital terrain elevation maps and remotely sensed information. Once parameter values have been determined, physically-based models can be used for a wide range of applications and require less frequent recalibration.

The Representative Elementary Watershed (REW) model is introduced as a physically-based hydrological modelling approach, which is based on the use of control volumes. Governing equations are integrated over topographically defined spatial regions and can be solved numerically or analytically as ordinary differential equations. Several case studies are presented, in which the REW model is used for operational flood forecasting and surface-groundwater interaction studies. The selected cases include the application of the REW model to the river Mosel basin in Germany, the Tamar basin in Cornwall, UK, as well as the Geer basin in Belgium.

7. Hydrologic Modelling System (HEC-HMS)

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The Hydrologic Modelling System (HEC-HMS) is a fully-featured multiple purpose surface hydrology and river modelling system that can be used to perform flood forecasting. It includes simulation components for all segments of the hydrologic cycle. Precipitation can be modelled with grids (radar) or observation gauges, and snowmelt can be included if required. Infiltration can be modelled for single storm events (Green and Ampt, SCS curve number) or continuously (simple or complex tank model). Overland runoff can be modelled with a unit hydrograph, kinematic wave, or conceptual semi-distributed grid cells. Flood wave routing can be performed with Muskingum, modified Puls, kinematic wave, or Muskingum-Cunge variable parameter.

Reservoirs and diversions can also be included.

The U.S. Army Corps of Engineers uses HEC-HMS to plan daily operations at reservoirs for flood reduction, hydropower, and environmental goals. The watershed area is usually greater than 1500km2 and the forecast lead time is usually 3 to 7 days. Most watersheds have land use of agriculture, forest, or rangeland with moderate land surface slope. The watersheds may have no snow, transient snow, or deep winter snow pack.

The HEC-HMS software and documentation is available free from the internet at www.hec.usace.army.mil/software/hec-hms. The next release will include a new tool designed to simplify the process of making flood forecasts.

8. The descriptive material on FEWS Model

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FEWS (Flood Early Warning System) Pakistan was developed by Delft Hydraulics (Netherland) with the collaboration of NESPAK and Pakistan Meteorological Department.

FEWS Model employs two major analysis procedures for estimation and propagation of flood waves in the Indus River System. For this purpose it consists of following two modules:

i. SAMO (Sacramento): Rainfall-Runoff Model

ii. SOBEK: Routing Model

These procedures are Rainfall-Runoff and Routing models which estimate flood hydrographs from rainfall in the upper catchments of the rivers and their tributary streams and compute flood and stage hydrographs at various points of interest along the river reaches in the plain areas.

SAMO (Sacramento) is a Rainfall-Runoff Model which conforms to the important phenomenon of hydrological cycle such as rainfall, evaporation, infiltration and base flow. It has a small computational time interval and can analysis a watershed which has been divided into several smaller parts, each having its own parameter set of evaporation rate and rainfall.

The rainfall of past 24 hours, recorded through telemetric stations, meteorological observatories, radar observations and as Quantitative Precipitation Forecast (QPF), manually estimated rainfall or forecasted quantitative rainfall of UGRIB are given as input to SAMO to produce runoff at the rim stations of River Jhelum, Chenab, Ravi and Sutlej and also of the tributaries, downstream of rim stations of five man rivers.

i. River Indus: SAMO Model for the upper catchments area (above Tarbela) and its main tributary river Kabul has not been developed and incorporated in the FEWS Model.

ii. It covers all the upper and lower catchments areas of Rivers Jhelum, Chenab, Ravi and Sutlej and downstream of Tarbela.

SOBEK include morphology of main rivers and characteristics of hydraulic structure / Barrages.

SOBEK is one dimensional hydrodynamic river flow model based on Saint-Venant equations of unsteady flow. Level in meter and flow discharge in m^3/s, recorded at hydraulic structures/ Barrages and Dams for the past 24 hours, and as forecasted flows at the rim stations is given for routing. It is developed using the physical description of the geometry of rivers, continuity equation and a balance of forces governing the flow of water in open channels. It can properly represent the influence of bridges, barrages and dams on the propagation and attenuation of flood waves. The different roughness values and storage characteristics of a river can be considered. The Model for River Indus and its major tributaries have been calibrated below the rim station using river cross-section (6 Km apart), river roughness, rating curves, discharge and elevation series for a given year.

During calibration process, discharge series at the upstream end of a river reach and water elevation series at its downstream end have been used as boundary conditions. The model computes water elevations and discharge along a river reach which are checked against the observed data and the river characteristics are revised to closely match the computed and observed data. The calibrated model is then validated for the other years.

During the real time forecasting, SOBEK is used to predict water level, discharges and extent of flooding along a river reach. It takes discharge value at the Rim stations and routes it downward up to Kotri by giving highest discharge value along with level with date and time at all the main barrages.

9. Flow forecasting for the rivers Rhine and Meuse in The Netherlands

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Water level forecasts for the Dutch rivers Rhine and Meuse are of great importance for operational flood management in The Netherlands. These forecasts are a responsibility of the Dutch Centre for water Management. Under normal conditions the Centre publishes daily forecasts for the River Rhine, mainly on behalf of the navigation on the Rhine. In periods of flood the frequency of forecasts increases to maximum four times a day. Flood forecasts for the Rhine at the German Dutch border are published when the water level at the gauging station Lobith rises to 14 m above mean sea level and further rise to at least 15 m is expected, a situation that occurs approximately once a year.

Until January 1999 a statistical model based on multiple linear regression was used for daily as well as for flood forecasting. After the large floods in 1993 and 1995 it was clear that a new more physically based modelling approach was necessary, which led to the development of the current forecasting system FEWS Rivers. FEWS Rivers is a combination of hydrological (HBV) and hydraulic (Sobek) models, developed for short as well as for medium range forecasts (4 – 14 days). It uses multiple weather forecasts, both deterministic and probabilistic.

FEWS Rivers was used operationally during the January 2011 flood on the Rhine. During this flood it became clear that further improvements in the system, e.g. snow melt modelling are necessary.

10.Flood Forecasting on continental scale

Jutta Thielen, Peter Burek, Konrad Bogner & EFAS team

European Commission, DG Joint Research Centre, Ispra, Italy

Continental systems such as the European Flood Awareness System (EFAS) are complementary to local, regional and national flood forecasting systems and fulfill an important role in providing overview information on floods across administrative boundaries, e.g. for entire river basins and across borders. This information is important for international civil protection when planning and organizing aid for crisis situations and for national systems as added value information. They serve also in filling gaps for those regions where flood forecasting system do not yet exist or are not active. Heavy calculations necessary for probabilistic approach is done centrally. While continental systems cannot be as detailed as local systems, they are based on distributed, hydrological models and methodologies that are applied in the same way across the continent, and can therefore serve as reference information

The European Flood Alert System is based on the LISFLOOD model, a spatially distributed rainfall-runoff model with a channel routine component. Its aim is to predict probability of floods 3-10 days in advance. It is set-up on a 5x5 km2 grid and runs on 6h- 24h time steps. It is driven with multiple weather prediction inputs including the full range of deterministic and ensemble prediction products from the European Centre for

Medium-Range Weather Forecasts (ECMWF), deterministic weather forecast from the German Weather Service (DWD), and limited area model EPS from COSMO. Crucial for the set-up and calibration of the model are good data sets of historical and real-time meteorological observations from station data, which are collected on a 24/7 basis and used to calculate the start-up conditions of the forecasts.

EFAS information is based on threshold exceedance approaches : from long-term simulations certain return period thresholds are calculated and all forecasts - using exactly the same model set-up and parameterisations - compared against those thresholds. It has the advantage that systematic under- and overestimations are cancelled out and alert information is more robust. At those points where real-time discharge data is made available by the EFAS partners, post-processing of the discharge forecasts are performed and the results converted into bias-corrected discharge probabilities, which combines the results from the multiple inputs into one output.

During the 2010 floods in Central Europe, the EFAS was used for the first time in close collaboration with the MIC for improved upfront planning of the crisis management affecting several countries as well as keeping the crisis staff informed during floods for keeping an overview of necessary actions to be taken.

In analogy to the European Flood Awareness System and in collaboration with ECMWF, the JRC is also developing a global flood awareness system. It is slightly simplified in its hydrological model components, but represents a system with full calculation of the hydrological processes and routing.

The challenges faced by setting up continental flood forecasting systems are first of all availability and quality of data, e.g. GIS, historic and real-time observations and event descriptions, need of specific training for complex systems with novel content, e.g. communication of probabilistic results in a context where deterministic solutions are expected, and adaptation of a “one solutions system” to different geographical and climatological regimes.

11.Scales and Predictive Uncertainty: two bottlenecks to Operational Forecasting and Decision

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Recent developments of real time flood forecasting systems include the use of several hydrometeorological inputs and forecasts, such as Radar and quantitative precipitation forecasts. This has put in evidence on one hand the need for developing new distributed hydrological models at finer scales and on the other the need for assessing predictive uncertainty.

Due to the fact that most of the existing operational flood forecasting systems are based either upon statistical approaches or on lumped hydrological models, such as for instance NAM, HBV or ARNO, it will be shown that extrapolation to ungauged catchments can only be efficiently performed using distributed physically based models. In fact, the physical properties of the basic hydrological processes can only be retained at finer spatial scales in rainfall-runoff models, while, due to the inherent topological non-linearity, physically based lumped models can only be derived through an averaging process conditional upon a correct representation of additional phenomena, such as the soil filling and depletion hysteresis and the exfiltration at the end of a rainfall event, which presently can only be obtained via simulation using a distributed modelling approach.

Moreover, for quite a long time, traditional approaches to flood warning and flood emergency management have been based on the comparison of measured water stages with pre-determined “threshold levels” (warning, alert, flooding levels, etc.). The measured water stage values were generally considered as “deterministic” given the relatively small measurement errors (1-2 cm). In the last decades, with the aim of anticipating both decisions and the consequent emergency actions, the original water stage measurements have been substituted by hydrological or hydraulic model forecasts. By doing so, the model forecasts were implicitly assumed to be more or less of the same quality as the measurements generally disregarding the impact of large forecasting errors over decisions. Fortunately, the recent introduction of the predictive uncertainty concept has created the prerequisite to change the original “deterministic threshold” paradigm into a new “probabilistic threshold” paradigm.

Probabilistic forecasts, in terms of a correct definition of predictive uncertainty, not only allow to set up probabilistic decision thresholds but also allow to combine the information of several forecasting models of different nature, such as distributed physically based, lumped hydrological and data driven models.

12.HYDROLOGICAL FORECASTING SYSTEM (WSFS) IN FINLAND

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WSFS (Watershed Simulation and Forecasting System) is widely used in Finland for real time hydrological simulation and forecasting. WSFS development has started from a rainfall-runoff model with the same basic structure as the HBV-model widely used in Scandinavia. WSFS covers the land area of Finland including cross-boundary watersheds, 390 000 km2. The distribution of the model is based on the third level watershed division with 60 - 100 km2 sub-basins. In research version 1x1 km2 grid is used. Main meteorological inputs are precipitation, temperature and cloudiness. Simulated variables are areal precipitation, evapotranspiration, lake evaporation, snow, soil moisture, surface, sub-surface and ground water flow and storage, runoff, discharges and water levels of rivers and lakes. An elevation model is included to simulate effects of elevation and slope gradient on areal precipitation, temperature, snow accumulation and melt. Land-use, vegetation and soil type data are used to simulate snow and to develop simulation of soil moisture, soil frost and evapotranspiration. A nutrient (phosphorus, nitrogen and solid sediments) simulation model covering also whole Finland is developed and operational based on hydrological simulation model.

Remote sensing data used in the system are satellite data of snow cover extent and water equivalent and precipitation from weather radars. Assimilation methods for the use of satellite snow data in WSFS have been developed for operational use. Assimilation methods of flood area and soil moisture (SMOS) data from satellites are under development. Weather radar has been in operational use since 1998 and is still under development to increase the accuracy of weather radar areal precipitation estimates. Weather radar gives more realistic rainfall distribution estimates than gauge network. In summer, gauge measurements can be replaced by radar precipitation. In winter, snow accumulation simulation using only radar data is not possible.

Automatic model updating system developed in SYKE is an important part of the WSFS. Model state updating is done against water level, discharge, snow line and satellite snow observations. The updating procedure corrects the model simulation by changing the areal values of temperature, precipitation and potential evaporation (i.e. finally the corresponding storage) so that the observed and simulated discharges, water levels and snow values are as equal as possible. The WSFS obtains daily meteorological data from 200 precipitation and 40 temperature stations, weather radar precipitation over 300 000 km2. Updating of WSFS is done against 160 water level stations, 130 discharge stations, snow covered area and water equivalent over Finland from satellites and against 178 snow lines obtained once or twice per month.

Main operating part of WSFS is the distributed hydrological catchment model over Finland, model updating software, data collection and forecast transfer software, www-user interface for lake regulation control and data storage and www based forecast distribution. WSFS is connected to hydrological registers and real-time observation network, to synoptic weather station and weather radar network of the Finnish Meteorological Institute (FMI). WSFS obtain weather forecasts (VAREPS, monthly and seasonal EPS) from European Centre of Medium-Range Weather Forecasts via FMI. In operation WSFS automatically collects meteorological and hydrological data from the registers, runs hydrological forecasts and distributes forecasts into the Internet www.environment.fi/waterforecast and registers for different users.

13.Summary of Presentation: Flood Warning in Bavaria, Germany

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Timely warning of flood hazard is an essential part of precautious flood protection. But effective flood mitigation also requires the preparedness of the recipients. The flood warning service in Bavaria has performed valuable work for successful mitigation of flood damage for more than 100 years. It covers the river basins in Bavaria with response times ranging from 6 to 12 hours through to the larger basin of the Danube with response times ranging from 1 to 3 days. Five flood forecast centres corresponding to the main river basins (Main, Danube, Inn) and tributary basins where large reservoirs have to be operated (Iller-Lech, Isar) are responsible for operational flood forecast. They closely co-operate with the flood information centre and the 17 state offices for water management. Transboundary water courses like the Danube and Inn river in Bavaria requires a close cooperation with Austria in terms of flood forecast and flood warning and has led to a unique forecast system in these basins.

As a prerequisite for flood forecast a meteorological and hydrological information system and database with a fully automated data communication system has been created in the last ten years. The focus was on the reliability and availability of the main system-parts. Real-time data collection, online data base, generation of automated products and the dissemination of the data and products are based on redundant systems at several locations.

Hydrological forecasts have become an important part of the flood warning scheme since they are calculated for all river basins in Bavaria. For large parts of Bavaria, flood forecast models of modular structure have been developed, verified and adopted. The hydrodynamic models WAVOS (Danube and Main) and FLORIS 2000 (Lech, Inn and Danube) are in operation. For the tributaries, distributed rainfall–runoff models based on the program LARSIM are implemented. They are grid (1x1 km) or sub-basin oriented. Numerical weather forecasts of the German Weather Service (DWD) are mainly used as input to the hydrological forecast models. The latest product is the short-term precipitation forecast using the results of online-adjusted radar. Development of snow cover and the total water release from snowmelt and rainfall is pre-processed by the results of the SNOW4-model of the DWD.

Experiences with published forecasts during former flood events have shown the need for communicating the uncertainties associated with these forecasts to the civil protection and the public. Therefore, methods for quantifying and representing these uncertainties have been developed and incorporated in the flood warning routine.

14.Overview of flood forecasting: Different Continents, Conditions, Boundaries, Challenges

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The objective of this presentation is to provide an overview of approaches taken in flood forecasting across the world. Although it is difficult to generalise the challenges faced, the presentation illustrates these through looking at example basins in each of the continents.

First the presentation looks at the Rhine basin, and in particular the service provided by the Swiss Federal Office for the Environment. Forecasting is very well developed here and there is a close collaboration with users of the forecast as well as professional partners. Data from an extensive network of hydro-meteorological stations is used, and the HBV conceptual hydrological model being used, as well as several meteorological forcing products. Some current challenges lie in the integration of physically based models for selected basins to replace the lumped HBV model, as well as the integration hydro-meteorological data from additional (regional) networks.

In the Columbia basin, in the Northwest of the United States, forecasting is provided by the National Weather Service Northwest River Forecasting Center. As with the Rhine basin, forecasting capabilities are well developed, with extensive observed data sets being integrated into the very comprehensive coverage of hydrological models. Currently some of the challenges that are tackled lie in the scope of the Community Hydrological Prediction System (CHPS) program, which aims to engage with the wider community involved in hydro-meteorological forecasting and through this improve the service provided. Additionally, challenges in moving to gridded forcing of the forecasts, as well as data assimilation and verification are being tackled.

These challenges are quite different than those faced in the Mekong basin in South-East Asia. Here the Mekong River Commission provides forecasts at the basin level, which is used as guidance to the national forecasting agencies of the riparian countries. Although the systems used are quite advanced, the main challenges are in the availability of (rainfall) data, in particular over the parts of the upper basin, with satellite rainfall being used as a surrogate. Another challenge is the sustainability of knowledge following changes in staff.

Similar issues are also faced in the Eastern Nile Basin in Khartoum, Sudan by the Ministry of Irrigation and Water Resources. A forecasting system was initially installed in 1992 using the then state-of-the-art in modelling and data assimilation. However, staff turnover and technical challenges led to the system quite quickly becoming defunct. This system has been recently revived, but rather than use models which have a very narrow knowledge base in Sudan, the HEC line of models is now used as these are more widely used in Sudan. This will help embed the forecasting system in the knowledge community in Sudan, thus improving sustainability of a continued operation of the system.

In the Zambezi basin in Southern Africa, forecasting is not yet developed at the basin scale. Whilst there are some forecasting systems, run independently mainly by reservoir operators, the challenges lie in establishing a central forecasting service that caters to all stakeholders, and provides a valuable service to all. The sharing of data from the eight riparian countries is key, as well as the maintaining and integrating of existing knowledge and models as much as possible to ensure stakeholder buy-in. The Magdalena River in Colombia in South America faces similar issues, thought there are very little forecasting capabilities currently developed. Again challenges lie at the technical level, as well as at the institutional roles and responsibilities of forecasting.

Finally a look is taken at a community based forecasting system in the West Rapti Basin in Nepal. This is a very small scale and technically simple system, but has been set up in and with the community. This has been proven to be of significant added value in the community when responding to flood events.

Overall the presentation shows that in many of the well established forecasting systems challenges lie in dealing with data and models, while in basins with less established forecasting capabilities, these are compounded by institutional challenges of forecasting at the basin level, as well as the challenge of poor data coverage.

15.HYDRIS II Hydrological Information System for flood forecasting in Salzburg / Austria

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The federal republic of Austria covers an area of 83.879 km² and consists of approx. 8 million. inhabitants. According to the Water Act 1959 in its present version, the Governors of the federal provinces are responsible for flood warning and therefore several hydrological models (Cosero, Larsim, HBV based, MIKE etc) are used for flood forecasting in nine independent flood-warning centres.

Austria's topography is the reason for clear flood seasonality patterns - summer floods due to orographic and convective rainfall, winter floods a quite rare - as well as for specially flood prone regions along the mountain ranges of the Northern Calcerious Alps and Central Alps. Flood warning has a long history in the Province of Salzburg, the present warning system is intended as a 3 stage model (Early warning, Pre warning, detailed forecast) based on different lead times up to 72 hours.

Precipitation and temperature forecasts from the central Met office (ZAMG) based on INCA (Integrated nowcasting with comprehensive analysis) are used as an input for HYDRIS II, which is based on COSERO, developed by BOKU Vienna, is a continuous semi-distributed run off model using HRU's, sub-catchments and 1 x 1 km grid cells.

FLUX/FLORIS, a 1 D hydrodynamic model is used for river routing and FEWS (flood early warning system developed by Deltares) combines all the modules in order to present the results on a graphic interface.

HYDRIS II covers a catchment area of approx. 6700 km² (i.e. 75 % of Salzburg) , 99 hydro-meteorological stations, 44 gauges and 18 hydro power stations are the backbone of the system operating on a 15 min basis. It is run by the Hydrological Service of Salzburg in cooperation with two hydro power companies (Salzburg AG and Verbund Austrian Hydro Power) and used to produce hourly forecasts used in official floodwater management.

HYDRIS II is also a part of the flood forecasting system for River Inn and hourly forecasts for the next 48 hours are transmitted downstreams.

Limits and uncertainties of forecasts based on precipitation forecasts are also an important issue and need to be transported to the "costumers".

Last but not least well trained and highly motivated staff with lots of experience, permanent adaption and improvement of the model as well as preparedness for all possible scenarios are key factors for a successful operational flood forecasting model.

16.Operational flood forecasting in France

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The French flood forecasting system has been built, and is still being improved, in order to fulfill the commitments of the early warning procedure, called “vigilance”. For flood warning, the access to the national and local maps, bulletins and real-time data is opened to the public since July 2006 through the internet on http://www.vigicrues.gouv.fr. SCHAPI, the national flood forecasting center, and the 22 regional services are responsible for the surveillance of 20,800 km of main rivers, divided into 250 river sections. About 1400 water level gauges are located on this network and used for various purposes, from observation, indication of tendencies to numerical forecasts. Up to now, the forecasts are provided in the form of a colour code for the 250 sections, as well as numerical values at selected stations on attached pdf files. The access to graphical representations of the forecast on the real-time limnigraph is under study. One additional aspect, which needs to be considered when building the system, is the time constraint between the access to new rainfall forecasts up to the production of new flood forecasts. In the case of the French system, this must occur within less than one hour at the level of the 22 local services, in order to meet the deadline of the single vigilance procedure between meteorological risk (produced by Météo France) and hydrological risk (produced by the state services).

Thanks to the experience of the last years, general rules have been agreed, and are being followed in the majority of cases, for selecting tools for the forecasting activities (warning colour codes on river sections and numerical values at selected stations. These are:

- License free tools,
- Open source tools to adapt them to special needs, in particular real-time chains, and to launch open tenders,
- Tools used by several services,
- Tools able to integrate latest methodologies (XML data exchange, grids, ensemble rainfall forecasts, assimilation…),
- Limited number of tools (mutualisation, cost reduction)
- Better possibility to organize teaching courses for selected tools

Then, more detailed rules have also been discussed by the state services when selecting the type of models to be implemented within the river sections. For example, for sections governed by rainfall-flow relationships, three steps have been identified, such as:

- Begin with empirical models on the in-house developed SOPHIE platform (PQb, linear relationship, multi agents...), with possibility to create models for various categories (flow or forecast intervals) or multi-models

- If better results are needed: use a GRP model (lumped model with rainfall forecast)

- If better results are needed, or if rainfall distribution is important: use the distributed ATHYS platform

The same type of procedure has been defined for sections governed by propagation, and for sections under marine influence.

When considering the robustness and adequacy of the flood forecasting system, major issues seem to be the availability of improved forecasts of the rainfall field, the security of the operational procedures under degraded conditions, and the communication between the technical operational services and the end-users, in particular the services of the civil security.

17.Criteria for use of flood forecasting models: The French experience

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Since the reorganization of the services responsible for flood forecasting in 2003, a network of about 21 000 km of main rivers is under the surveillance of 22 regional flood forecasting services, 15 hydrometric services and the national coordination center, called SCHAPI. This river network is divided into some 250 sections, for which forecasts are provided twice daily, and more in the case of foreseen or current flood. On a public website (http://www.vigicrues.gouv.fr), these forecasts are expressed in colour codes, called vigilance colours (from green, yellow, orange to red) for the river sections, as well as in discrete numbers at stations when a flood is occurring.

In order to develop a forecasting system adapted to the needs of the end-users and requirements of the legal documents, several issues are considered, such as:

1. The expectations of the end-user, the state services in charge of the warning and security of citizens, are legally documented following a detailed procedure, going from large regional management schemes to the selection of localized forecasts at relevant stations, located in vulnerable areas.

2. For each of the river sections, the hydrological context and vulnerable areas are described by the regional services, including hydrological behaviors, water works, historical records, and precipitation regimes. Threshold levels are set in relationship with past events and the level of flood risk are defined following the national colour scale.

3. A list of criteria is discussed by the forecasting teams to select suitable tools, including for example the anticipation needs at the forecasting stations, the adequacy of the tools (type, speed, consistency…) to the hydrological behaviour, the availability of former events, the ease of use and maintenance, the possibility of running with degraded conditions, the need for expertise of the forecasting team. This work allows one to select the type of relevant forecasting tools, such as hydrological rainfall-runoff models to 2D hydraulic models, for the river sections and at the forecasting stations.

4. The inventory of the existing operational tools, ranging from simple tables, empirical relationships, to 2D models is performed and evaluated in order to determine if the expected anticipation and accuracy of the forecasts can be reached by the available tools, or if additional models should be developed.

5. Additional improvements of the system are defined, such as the development of a methodology to evaluate the performance of the real-time forecasting, the integration of assimilation techniques within the rainfall-runoff and hydraulic models, the identification of procedures enabling to speed up the modelling system and the decision making of the forecasters (e.g. a real-time modelling interface), the extension to the forecast of flooded areas and flash floods.

6. Special activities are set to consolidate the capacities of the forecasters, including detailed return of experiences, courses, seminars…

7. Further improvements are expected through the exchange with partners, for example to improve the gauge network (data producers), to use the existing knowledge (scientists, other forecasters, e.g. electricity producers), to assess the results (civil security, mayors, decision-makers), to advice on further needs, such as anticipation, improved forecasts (decision-makers), and to improve the communication tools (decision-makers, media, public).

18.XinAnJiang Model

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Xinanjiang model is the first and the most famous rainfall-runoff model in China. It has been widely and successfully used for flood forecasting in humid or semi-humid regions in China for 30years. Among the seven large river basins in China, four of them are managed using this model. it has also become widespread in use, and influential in fostering further development of such models worldwide.

In this presentation, the lecturer has given a general introduction of Xinanjiang model, including the back ground of its origination, development, application in China and overseas, as well as its developing potential and promises future. Xinanjiang model is a lumped model based on the concept of “Runoff yield at natural storage”, its principle and structure are very clear and uncomplicated, there are only fifteen parameters in this model and divided into four groups according to the relationships between each other. The details about the principle, structure, parameters and calibration of Xinanjiang model as well as some case study are introduced in this presentation. In addition; some special points related with Xinanjiang model, such as operational setting, scaling issues (space / time), boundary conditions, calibration/ validation, limit of forecasting, reliability, uncertainty etc. are also presented

Annex 2: List of participants of expert meeting

World Meteorological Organization

ihp·hwrp germany
German IHP/HWRP National Committee

CHR KHR
Commission internationale de l'Hydrologie du bassin du Rhin
Internationale Kommission für die Hydrologie des Rheingebietes

The Netherlands National Committee IHP-HWRP

List of Participants

WORKSHOP ON INTERCOMPARISON OF FLOOD FORECASTING MODELS

14 – 16 September 2011, Koblenz, Germany

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