



## Training Module

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### Flood Disaster Risk Management- Hydrological Forecasts: Requirements and Best Practices

A. Vogelbacher





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Flood Disaster Risk Management-  
Hydrological Forecasts: Requirements and  
Best Practices

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## Message



Dr. Dieter Mutz  
Director  
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New Delhi, February 2013

Since 2010, GIZ has been collaborating with the National Institute of Disaster Management for implementing the “Environmental Knowledge and Disaster Risk Management” project, aimed at strengthening capacity building initiatives in knowledge management and risk reduction for disasters caused by natural hazards, such as floods, cyclones, drought, or manmade disasters caused by industry. The design and development of training tools, such as an internet based training and knowledge management system and blended learning training methodology and the development of training materials are important activities under this project.

It gives me great pleasure to introduce the Training Module, Hydrological Forecasts - Requirements and Best Practices. I hope the case study will help trainees in developing better understanding of the flood early warning, forecasting and dissemination mechanisms.

I take this opportunity to express appreciation of the commitment of NIDM, Ministry of Home Affairs, Government of India, New Delhi, the Flood Information Centre, Bavarian Environment Agency, Munich, Germany and ifanos Germany and India who made this effort successful. I wish that such modules are used extensively by all stakeholders across the country.



## Foreword



Dr. Satendra, IFS,  
Executive Director,  
NIDM  
New Delhi, February 2013

Knowledge of environmental systems and processes are key factors in the management of disasters, particularly the hydro-meteorological ones. Climate-change is the challenge of modern times known to aggravate natural hazards like floods, drought, cyclone, landslides and forest fires, and on the other hand it also intensifies people's vulnerability by affecting their resources and capacities. Environmental conditions including climatic and topographic factors also determine the dispersion, transport and thereby, the fate of chemical incidences.

NIDM and GIZ Germany, under the aegis of Indo-German Environment Partnership Programme (IGEP) with Indian Ministry of Environment and Forests, implemented a joint project entitled "Environmental Knowledge for Disaster Risk Management (ekDRM)" wherein development of case studies and training modules are the key activities.

I am pleased that the five modules are developed under the project viz.

- Environmental Legislation for Disaster Risk Management
- Disaster Risk Management using Knowledge - Base and Statistics
- Flood Disaster Risk Management - Gorakhpur Case Study Module,
- Hydrological Forecasts - Requirements and Best Practices: Case Study Module
- Critical Infrastructures and Disaster Risk Reduction in the Light of Natural Hazards

The Case Study Module Hydrological Forecasts - Requirements and Best Practices demonstrates with example of operational flood forecasting, flood warning and dissemination systems in Bavaria and its comparison with India.

The efforts made by the author are commendable and I hope the module shall be used by trainers, scholars and practitioners at different levels. I am sure, the modules shall be of significant contribution in the training and capacity building programmes within the country and outside. I welcome the views and suggestions of the readers for improvements in future.

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# 1

## Introduction

Flood hazards cannot be avoided and floods cannot be controlled fully by engineering measures. But the mitigation of the consequences can help significantly reduce the risk posed. Prerequisite of any effective mitigation of the consequences of flooding is a good understanding of the development of flood events and subsequently the provision of effective flood warning.

Operational flood warning systems that provide timely warning will reduce loss of life and property. Functioning warning systems are the basis to implement simple, yet effective measures such as evacuation, temporary relocation, or implementation of a flood control strategy. Additionally such systems are a cost-effective way of reducing flood risk and may help avoid large investments in traditional engineering flood control measures such as the raising of dykes or the building of flood Control dams.

However, early warning is not sufficient. It must be always complemented by ensuring that the information reaches the vulnerable on time. It requires the awareness and the preparedness of those to be informed and those that have the task to warn.

Operational flood warning systems have been developed or are under development in river basins worldwide. They all rely on the detection of floods through hydro-meteorological observation networks. The use of observation data is a primary element of a flood warning system. To increase the potential utility of the flood warning service through extension of the lead time of the prediction of a flood event, the state-of-the-art systems also incorporate some form of (model based) flood forecasting.

A wide range of techniques may be employed to provide flood forecasting capabilities, ranging from data-driven modelling techniques, through conceptual modelling approaches to more complex systems of conceptual and physical models (Werner et al., 2006).

This Case Study explores flood forecasting systems from the perspective of its position within the flood warning process. A method for classifying the different approaches taken in flood forecasting is introduced before the elements of a present-day flood forecasting system are discussed in detail. Finally, the state of the art in developing flood forecasting systems is addressed including how to deal with specific challenges posed.

The target group of this case study are decision makers in disaster risk management and/or water management. The case study should help to understand some hydrologic basics of the flood forecast and assist in the administration and implementation of an appropriate flood warning system in a specific environment, to find the best solution for a region.

Best solutions depend mainly on quality and availability of data, the areas and/or points of interest, catchment properties, cross border catchments, and financial capabilities with special consideration of flood forecast.

# 2

## LU-A: Floods- Hydrologic Basics

The most common cause of floods is intense rainfall. Flood occurs when it rains heavily and runoff is strong. Runoff is the most important component for flood prediction. Most dangerous flooding rainfalls are connected to certain weather conditions. For the extent and progression of a flood the percentage of the catchment area of a river affected simultaneously by rainfall plays an important role. A short, small-scale thunder storm can make an individual mountain stream into a raging white water, while the water level of a major river downstream fluctuates hardly. Only a steady rain that lasts long and covers a large area can overtop the banks of large rivers and streams. In the mountains melting snow can generate a large amount of runoff. The faster and more snow melts, the greater the burden on the rivers. Ice can impede the flow of water volumes.

Runoff is the portion of rain and snow melt water that moves toward a stream channel rather than infiltrating the soil. For some purposes, however, runoff also includes the subsurface water known as inter flow which also quickly moves toward the stream channel.

Mainly there are two flood types taken into consideration in this study:

- Flash Floods
- Riverine Floods (slow river floods)

A flash flood is a flood of short duration with relatively high peak discharge. It is a flood that rises and falls quite rapidly with little or no advance warning. The triggering event can be intense rainfall, the failure of a dam, levee, or other structure that is impounding water or the sudden rise of water level associated with river ice jams. As a fluvial flood, a flash flood is limited to relatively small catchments.

Riverine floods are medium or slow onset floods, which take a longer time to develop. This type of flood is connected to larger rivers and streams with larger catchments.

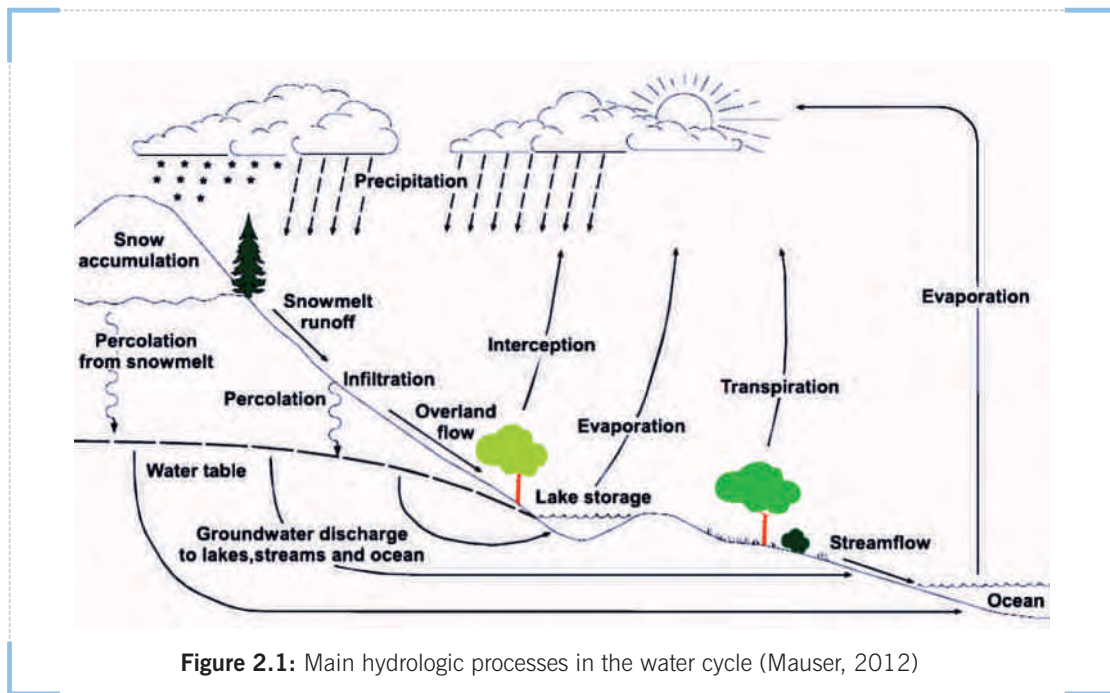


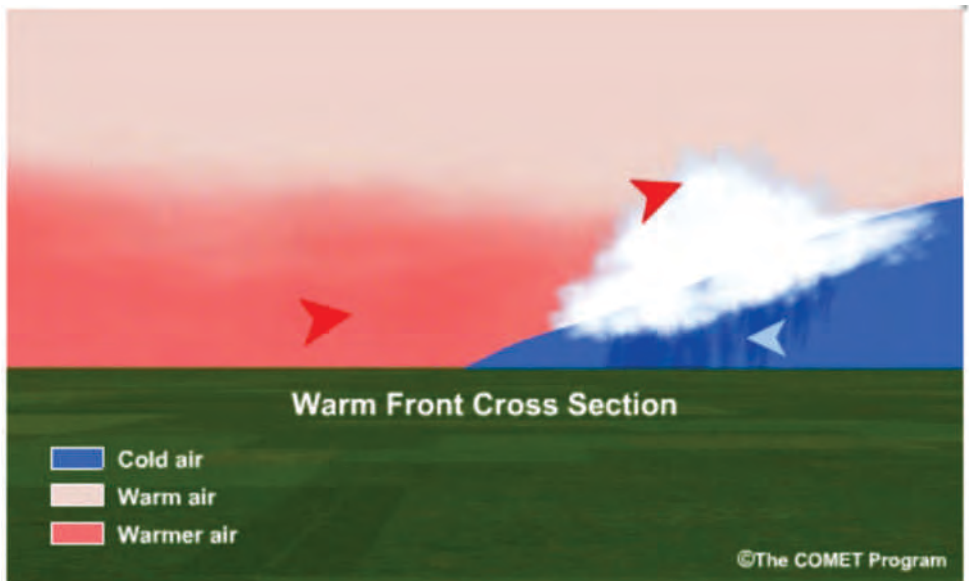
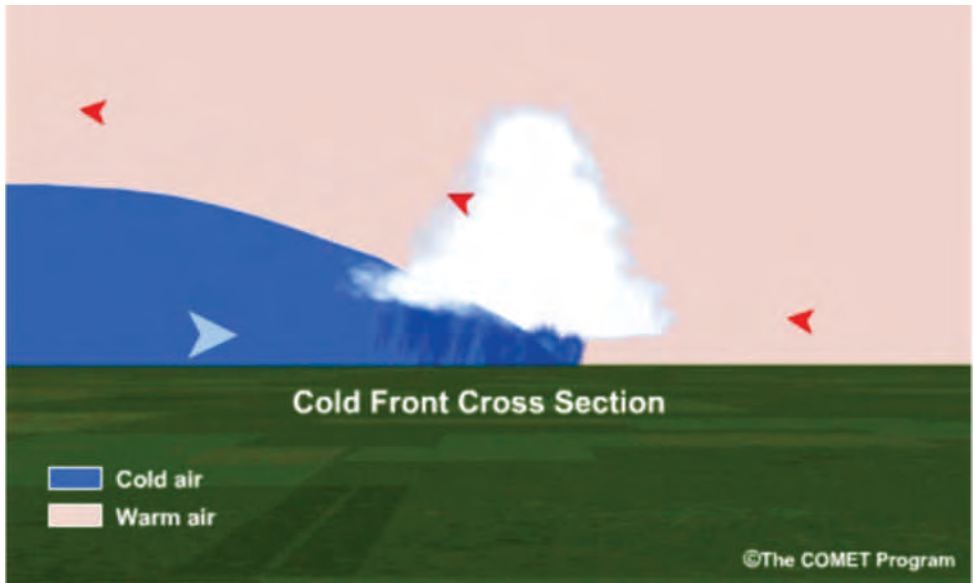
Figure 2.1: Main hydrologic processes in the water cycle (Mauser, 2012)

## 2.1 Rain

For the generation of floods two types of rain are of particular importance: prolonged large-scale rainfall and short but intense duration rainfall accompanied by thunder-storm.

Long lasting and wide spread rains have special influence on the extent of great river floods. This advective or cyclonic type of rain results from the convergence and subsequent lifting of air masses (cooling, condensation and growth of water droplets) in connection to a low-pressure area (cyclonic cooling). This type of storm may last from 24 to 72 hours and deliver a total of 50 to 150 mm. Tropical rains of this type may reach up to 350 mm in a period of 12 to 24 hours.

The frontal type of lifting occurs when the circulation forces air up over a frontal surface. Inflowing warm air can be lifted at hitting colder air (warm front). This results in moderate rainfall rates often of quite long duration. A cold front forces a rapid raising and cooling of the displaced warm air. The resulting weather may be tumultuous, with short-duration pelting rains and high winds.



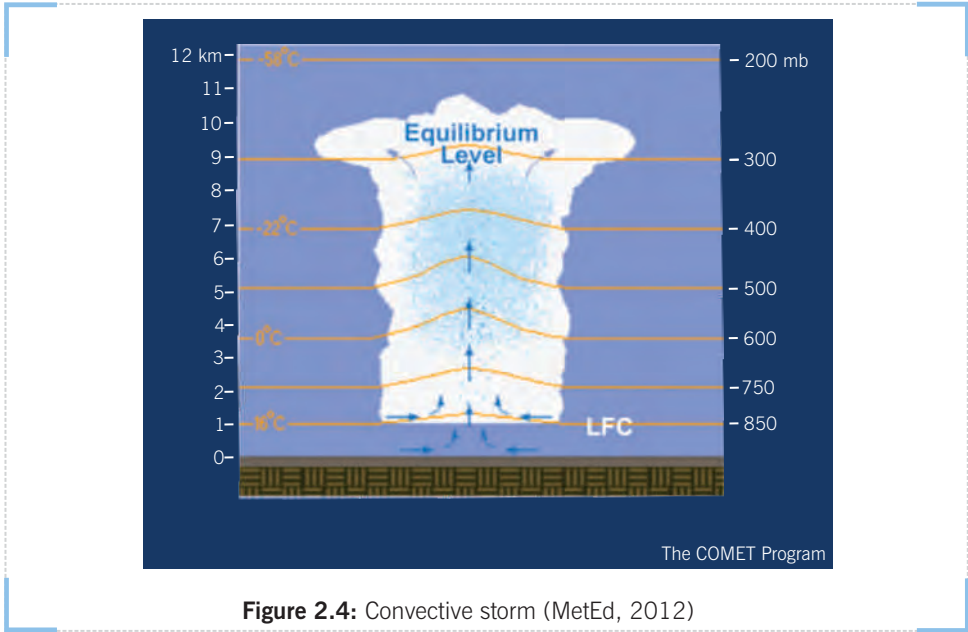
**Figure 2.2:** Cold front & warm front (MetEd, 2012)

When moist winds blow up a slope, the air will expand and cool at the lower pressure corresponding to the higher elevation (orographic cooling).



**Figure 2.3:** Orographic lifting (MetEd, 2012)

Convection currents (convective cooling) develop under the condition of vertical instability in the atmosphere. If the moist air temperature decreases by more than 6°C per kilometer it indicates unstable condition. This instability can be caused by surface heating. The air rises because it is warmer and less dense. The air is lifted to its level of free convection (LFC) and continues to rise as long as it is warmer than the surrounding air. Eventually, the rising air reaches an equilibrium level at which its temperature equals that of the surrounding environment (Figure 2.4).



**Figure 2.4:** Convective storm (MetEd, 2012)

During this process, moisture is condensing in the rising updraft air and forms rain-drops. The weight of the raindrops increases and eventually becomes too heavy for the updraft to hold aloft. Subsequently, precipitation will begin to fall back down through the updraft. The resulting rain is of very short duration, seldom more than 1 hour, but the intensities are very high and may amount to 70 to 100 mm. This con-vective type of rain can produce flash floods on streams with small catchments.

## Monsoon

In India floods occur mainly during the monsoon as over 80% of India's annual rainfall occur during this period. The south-western summer monsoons occur from June through September. The Thar Desert and adjoining areas of the northern and central Indian subcontinent heats up considerably during the hot summers, which causes a low pressure area over the northern and central Indian subcontinent. To fill this void, the moisture-laden winds from the Indian Ocean rush in to the subcontinent. These winds, rich in moisture, are drawn towards the Himalayas, creating winds blowing storm clouds towards the subcontinent. The Himalayas act like a high wall, blocking the winds from passing into Central Asia, thus forcing them to rise. With the gain in altitude of the clouds, the temperature drops and precipitation occurs. Some areas of the subcontinent receive up to 10,000 mm (390 inches) of rain annually.



The southwest monsoon is generally expected to begin around the start of June and fade down by the end of September. The moisture-laden winds on reaching the southernmost point of the Indian Peninsula, due to its topography, become divided into two parts: the Arabian Sea Branch and the Bay of Bengal Branch. The Arabian Sea Branch of the Southwest Monsoon first hits the Western Ghats of the coastal state of Kerala, India, thus making the area the first state in India to receive rain from the Southwest Monsoon. This branch of the monsoon moves northwards along the Western Ghats (Konkan and Goa) with precipitation on coastal areas, west of the Western Ghats. The eastern areas of the Western Ghats do not receive much rain from this monsoon as the wind does not cross the Western Ghats.

Southwest Monsoon flows over the Bay of Bengal heading towards North-East India and Bengal, picking up more moisture from the Bay of Bengal. The winds arrive at the Eastern Himalayas with large amounts of rain. Mawsynram, situated on the southern slopes of the Khasi Hills in Meghalaya, India, is one of the wettest places on Earth. After the arrival at the Eastern Himalayas, the winds turn towards the west, travelling over the Indo-Gangetic Plain at a rate of roughly 1–2 weeks per state, pouring rain all along its way. June 1 is regarded as the date of onset of the monsoon in India, as indicated by the arrival of the monsoon in the southernmost state of Kerala.

Like flash floods, monsoon floods are often caused by large amounts of rain falling in a short period of time. Flash floods, however, are generally localized. Monsoon rains tend to affect larger areas, causing more damage and higher loss of life. There may be multiple waves of flood during a single monsoon season. Each rainfall (new wave) poses more potential for flooding as large amounts of rain already saturated the ground and rivers are overflowing their banks.

**Weather summary (MetEd 2012):**

*Weather is complicated, develops across a range of spatial scales, and is ever-changing. Keeping up to date with potential weather hazards requires three things:*

- 1. Knowing what is going on now*
- 2. Knowing what is expected over the next several days*
- 3. Keeping track of what is happening upstream from your area*

## 2.2 Influences of land surface

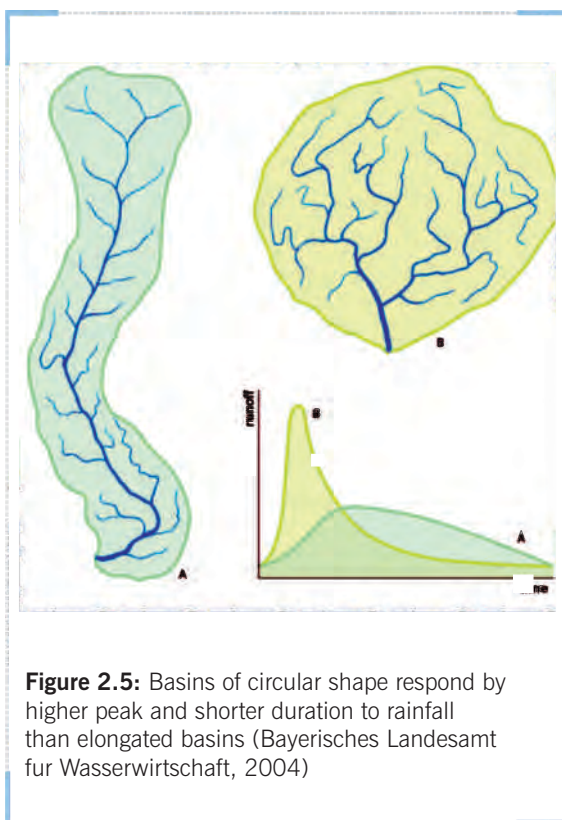
The properties of the land surface and soil have a major influence on the rainfall loss (this is the part of rain which does not contribute to direct runoff). Rainfall losses that are significant in analysing and modelling flood events include land-cover interception, depression storage, and infiltration. Evapotranspiration has a negligible effect in most flood events.

Interception and depression storage result from the retention of water on the surfaces of vegetation and in local depressions in the ground surface. Infiltration (the movement of water into the ground) is the most significant loss during flood events. The infiltration rate is highest among old forest stands and may reach 60-75 mm/hr. Under a meadows and pastures it may be 20 mm/h. The soil absorbs water like a sponge. Size and shape of the cavities in the soil determine its storage capacity and the infiltration rate. These vary depending on the humus content, soil type, soil thickness, and density.

Surface runoff originates either if the rain intensity exceeds the infiltration rate or if the total rain amount exceeds the storage capacity of the soil.

## 2.3 Surface runoff and runoff concentration

Surface runoff is collected by small creeks and rivers. This process is called runoff concentration. The catchment defines the area from where the water flows to a certain point in the river. The time of concentration is the time the water needs to travel from the most distant point in the catchment to the outlet. It depends mainly on the size and the slope of the catchment. The shape of the catchment has influence on the shape of the resulting flood hydrograph. A circular basin produces shorter and higher floods than a basin of elongated size.



**Figure 2.5:** Basins of circular shape respond by higher peak and shorter duration to rainfall than elongated basins (Bayerisches Landesamt für Wasserwirtschaft, 2004)

## 2.4 Snow melt

Beside rain, snow melt in winter and spring in the northern part of India provides a major contribution to floods. The amount of water stored in the snow pack depends on the condition of the snow pack. One centimetre powder snow corresponds to a rainfall of one millimetre of rain, which is one litre of water per square meter. Re-peated melting and freezing change the crystal structure of the snow and the density grows. An old snow pack is equivalent up to 4 mm rainfall per cm depth.

The energy budget of snow pack and its surroundings consists mainly of the following: incoming and reflected solar radiation, incident, and emitted long wave radiation, turbulent transfer of latent and sensible heat, ground conduction, and heat that is advected during rainfall.

The snow albedo or ratio of reflected solar radiation to incident solar radiation, decreases as snow ages, causing the snow pack to absorb more solar energy over time. Latent heat is the energy that is exchanged with the surrounding environment during a phase change of water. The latent heat of sublimation is about 8 times greater than the latent heat of fusion. The atmospheric vapour pressure above the snow pack can greatly affect how much sublimation occurs. Significant warming of the snow pack via deposition and subsequent latent heat release usually requires strong winds that induce turbulent transfer. When winds are calm, turbulent transfer is at a minimum, and any air that is cooled through sublimation near the snow pack surface remains near the surface. When winds are strong, turbulent transfer occurs, and mixes any cooled air near the snow pack surface with warmer air aloft. This can cause the melting process to begin, especially if winds are strong and vapour pressure increases with height in the atmosphere.

Rain falling on snow pack will impart some heat upon it. The amount of heat imparted depends on the temperature of the rain and any phase change that occurs. A rainfall 'warm' enough that it does not freeze as it trickles through the snow pack will impart small amounts of heat as it passes through the pack. A rainfall 'cool' enough that it freezes as it trickles through the pack will cause significantly more heat to be gained by the snow pack, as latent heat will be released to the snow during freezing. The amount of warming that occurs via rainfall freezing within the snow pack depends on the initial density of the snow pack.

When soil is unfrozen and unsaturated, melt water will be absorbed as long as the snow melt rate is less than the infiltration rate. When soil is frozen, infiltration of melt water is impeded. This can cause ponding and possible refreezing of melt water onto the ground. In rapid snow melt situations, this may cause flooding.

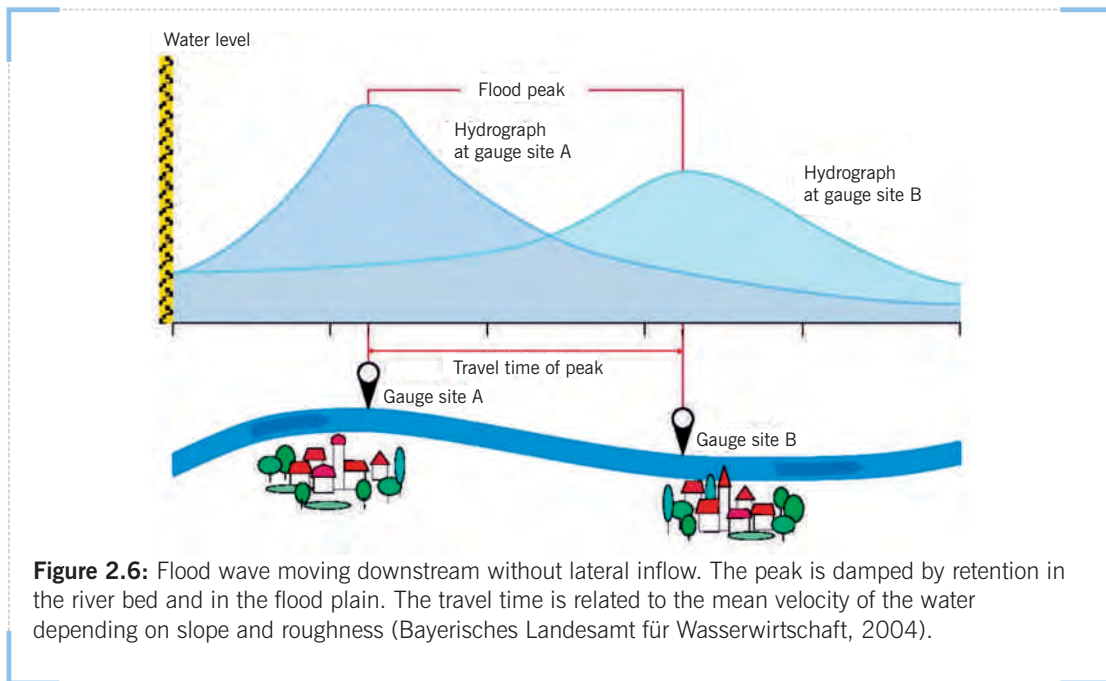
In the higher mountains, a thick snow pack is built up over the winter. Nearly all of the precipitation is stored as snow. Only a little water is discharged through the rivers. At the onset of warm weather in spring and early summer the snow melts off gradually. While in the valley the zero-degree mark exceeded already, a hundred

yards further up the slope there is still the frost. Only slowly the melting proceeds to greater heights. In the best case, the snow has melted in the lower regions and the water is already drained before the snow melts in the higher altitudes.

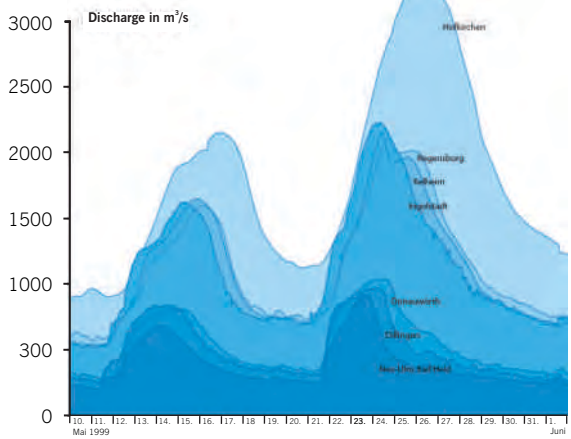
In the plains and hills no snow pack capable of storage is built up. The frequent changes between snowfall and rain has compacted the snow to high density. Because of the lower height differences, larger areas can be affected by snow melt at the same time releasing large amounts of water. Melting in the low mountain ranges is usually initiated by moist and mild air masses.

## 2.5 Channel flow and flood routing

Flood routing is the process of movement of a flood wave through a river system. The effects of storage and flow resistance are reflected in the shape and timing of hydrographs of the wave at different locations downstream. The travel time of the flood peak downstream is used for flood warning since ancient times. Tributaries in flood stage have a major influence on the travel time and height of the flood peak. If two rivers confluence when both are at the flood stage, the combination of flows can lead to a jump from a medium to a high flood.



**Figure 2.6:** Flood wave moving downstream without lateral inflow. The peak is damped by retention in the river bed and in the flood plain. The travel time is related to the mean velocity of the water depending on slope and roughness (Bayerisches Landesamt für Wasserwirtschaft, 2004).



**Figure 2.7:** Development of a flood wave downstream by flood routing and tributaries. The example shows the flood of May, 1999 in the Bavarian part of the Danube River. Between the gauges of Ingolstadt and Kelheim there was a dike breach clearly visible by the saddle near the peak in the hydrograph of Kelheim (Bayerisches Landesamt für Wasserwirtschaft, 2004).

**Important points to remember about flood science**

- A combination of high rainfall rate and very efficient runoff production is common to most flash flood events.
- In some situations the runoff characteristics can be as or more important than the rain rate.
- Soil moisture, soil permeability, soil surface alterations, and vertical soil profile are important soil characteristics that affect runoff production and hence help define flash flood prone areas.
- Basin characteristics, (e.g., size, shape, slope, land cover) influence runoff and hence flash flood occurrence potential.
- Urbanization and fire can greatly increase flash flood potential by increasing both the potential volume of runoff as well as the speed with which the runoff occurs.

(National Weather Service, 2010)

**Questions**

- How much rain leads to flooding where?
- How do basin and soil characteristics impact the generation of surface runoff?
- How will the water move once it reaches the ground?

# 3

## LU-B: Flood Warning Systems

The primary goal of a warning system is to prevent hazards from becoming disasters National Weather Service (2010).

There is a high diversity of flood warning systems in operation. Flood warning systems are typically tailor-made to suit specific requirements for the location for which the warnings are to be provided, ranging from fast-responding local warning systems in the headwaters of a river or urban areas to flood warning systems for lower reaches of large river basins. For example manual self-help systems (comprised of a local data collection system, community flood coordinator, flood forecast procedure, communication network to distribute warnings and a response plan) are inexpensive and simple to operate but may not have the best temporal resolution needed for short-duration accumulation and rainfall rates. The most simple flash flood alarm system consists of a water-level sensor(s) connected to an audible and/or visible alarm device located at a community agency with 24-hour operation.

Flood Warning Systems can be operated on a local, regional, basin wide, national, or even continental base like the Flash Flood Guidance (WMO, 2007). Often, flood warning systems are developed to cover all rivers within an administrative boundary, depending on the responsibilities of the authorities whose obligation it is to deliver the warnings.

The organization and structure of the system in adjacent regions or countries may be very different. In some cases, differences may even occur within the same river system, such as in the Rhine basin. No less than 25 flood forecasting and/or flood warning centres are involved from the source to mouth of the River Rhine, each with a different approach to flood forecasting.

Despite the apparent variety in approaches, the basic elements on which the effective flood warning depends are:

- detection,
- warning, and
- response

In the detection stage, real time data on processes that could generate a flood event are monitored. This includes primarily, monitoring of hydrological and meteorological conditions in the catchment through on-line information gathered through telemetry systems, climate stations, weather radar, and so on. In addition the detection stage may include the forecast system to increase the lead time of the warnings.

In the forecasting stage predictions are made of levels and flows, as well as the time of occurrence of possible forthcoming flood events. Typically, this involves the use of hydrological models, driven by both the real-time data gathered in the detection phase and forecasts of meteorological conditions such as rainfall and temperature. These are often obtained through external meteorological forecasts. Forecasting may also include now casting techniques such as storm tracking or propagation of moving rain fields in weather radar observations (Werner et al., 2006).

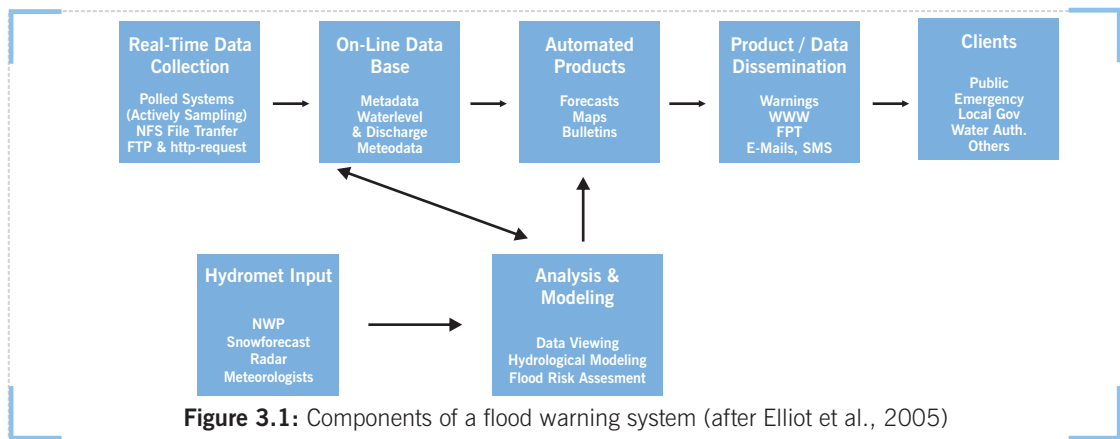
Flood forecast and warning may be triggered by monitoring rain and snow melt, water level or forecast of rain and snow melt. Threshold values have to be derived from the conditions of observed flood stages.

The warning stage is a key factor in the success of operational flood warning. Using information derived from the detection and forecasting stages, the decision to warn appropriate authorities and/or properties at risk must be taken. The warning must be such that it gives an unambiguous message on the imminent flood potential.

Response to flood warnings issued is vital for achieving the aims of operational flood warning. If the objective is to reduce damage through flood preparedness, an appropriate response by relevant authorities and affected persons must be taken following a warning.

Although flood forecasting is an important part of the flood warning process, the most basic warning systems do not include an explicit forecasting step even nowadays. The basic systems issue flood warnings on the basis of observations such as gauged rainfall and flows, combined with the judgment and experience of the forecasters.

Installing this basic system has to be the prior step before implementation of the forecast system. The goals of the forecast cannot be reached if the basic flood warning system is not implemented in a proper working manner.



**Figure 3.1:** Components of a flood warning system (after Elliot et al., 2005)

The Figure 3.1 shows the scheme of an on-line operational system used for flood warning. The figure follows Elliot et al. (2005) of the Australian Bureau of Meteorology with some minor modifications, but it can be taken as an example for other flood warning services, too. The upper series is a full automated chain beginning by real-time data collection for detection, sampling the data in a central data base, creating products like maps, forecasts, warnings and disseminate the products to the clients for warning.

### 3.1 Bavarian flood information service

Bavaria has set up a Flood Warning Service that follows the scheme in Figure 3.1 quite closely. It collects data of water levels, runoff and precipitation, analyses this information, draws up flood alert plans and warns people affected. Connected to the Flood Warning Service are the state offices for water management, the county district offices, towns, and communities. The coordinating unit is the Flood Warning Centre in the Bavarian Environment Agency (Figure 3.2). Five regional Flood Forecast Centres are responsible for calculating and preparing flood forecasts for the basins of the rivers Main, Danube, Isar, Iller/Lech and Inn respectively.

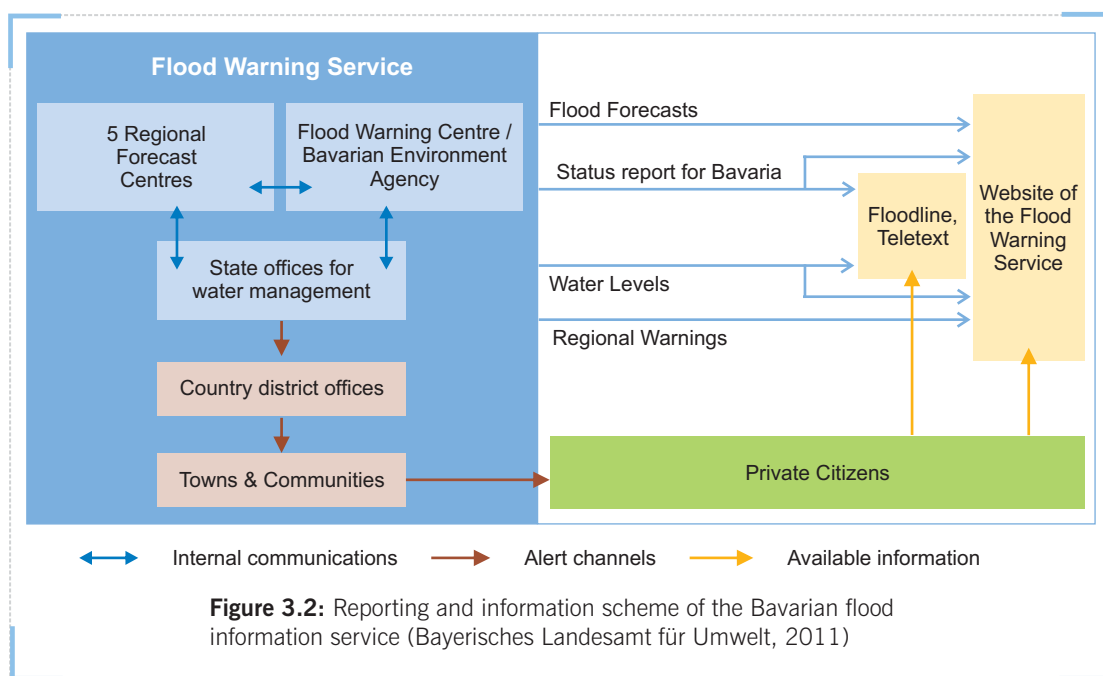
The respective centres are put into action as soon as rivers or lakes rise above defined threshold values. The water levels at the gauging stations are then read on an hourly basis and flood predictions are updated continuously. The state offices for water management put out regional alerts, while the Flood Warning Centre issues a flood status report for all Bavaria.

Alert plans make sure that this information is passed on through the county district offices to the affected towns and communities. Towns and communities are the last link in the alert channel and play a particularly important role. The alert plans specify who is to be warned, when and how, and what measures are to be taken at which gauge levels.



For this case, the local authorities have plans of endangered areas or buildings and plans for the organisation of flood defence systems.

The flood warnings have to be actively transmitted to the concerned recipients. Once warned, the recipients have the responsibility to inform themselves about the threatening flood. For this purpose, the state offices for water management, the regional flood forecast centres and the flood information centre provide updated data, forecasts and flood reports to the public and authorities via the website as well as flood news via a telephone service. Actual water levels of all gauging stations are provided via TV-text and telephone service.



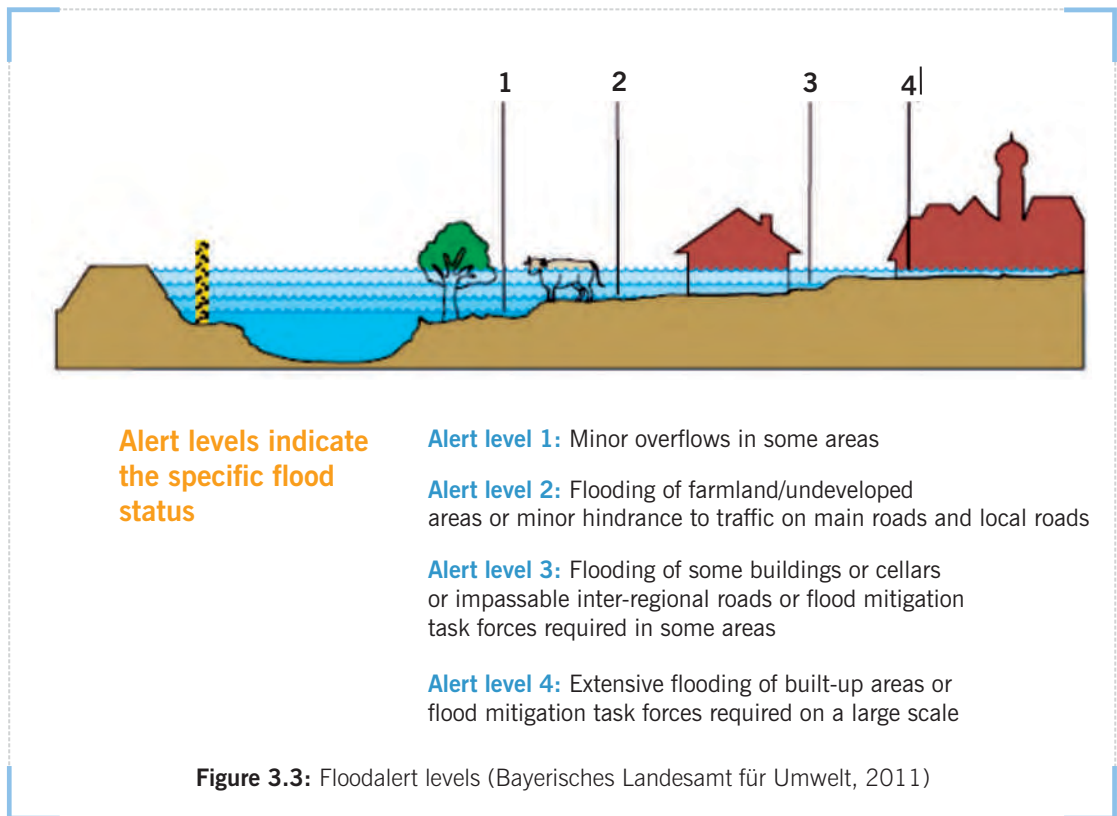
### Important points to remember about Flood Early Warning Systems

- One of the first steps in designing an Early Warning System (EWS) is to assess existing capability (and infrastructure) that could be employed by the EWS and what gaps need to be filled by new capability and infrastructure.
- Lack of forecast skill makes it very difficult to issue flash flood warnings several hours in advance based upon Quantitative Precipitation Forecasts (QPF). However, flash flood watches can be issued based upon QPFs and then later modified as necessary based upon observed rainfall (QPE).

(National Weather Service, 2010)

### 3.2 Water level and flood risk in Bavaria

The basic information in flood warning is the water level at the gauge site measured or forecasted. For interpretation in respect to the flood risk and to protective measures more information is needed. First, there are 4 alert levels that deliver plain and simple information on the extent of flooding. At each individual gauging station it is determined which water levels correspond to the respective flood alert levels (Figure 3.3). Second, there are tables for each gauging station connecting water level to a description of the flood extent, protective measures and flood hazard (Table 3.1). The communities are responsible for the maintenance of plans linking water level to flood risk and protective response. They keep plans of endangered areas or buildings and plans for the organisation of flood defence systems. Protective responses in Bavaria are: manageable flood polders, major storage dams in headwater, flood protection walls, mobile closures, superstructures, sandbags and evacuation.



**Table 3.1:** Flood hazards and protective measures in relation to the water level at gauging Station Passau Danube (cut version) (website [www.hnd.bayern.de](http://www.hnd.bayern.de))

W cm	Place	Type of measure or hazard
630	Passau	Advance warning to the police by the regulatory agency
720	Passau	Flooding of the upper Zollände in Passau and the harbour area Racklau.
720	Passau	Flooding of the Fritz-Schäffer-Promenade at the tavern -Tiroler-, removal of the motor vehicles.
740	Passau	Flooding of the Fritz-Schäffer-Promenade, traffic stoppage.
750	Passau	Evacuation of the parking lots at Schanzl.
750	Passau	Traffic blocking at the upper Donaulände
770	Passau	Flooding of the high road ST 2132 at Löwmühle
770	Passau	Evacuation of garages and souvenir shops at the lower Donaulände. flooding of the harbour area Racklau
780	Passau	Highest water lever for water navigation (HSW).
790	Passau	Flooding of the approach to the Nagelschmied- and Höllgasse
800	Passau	Flooding of the posterior Donaulände downstream of the Schanzl bridge.
800	Passau	Warning by loudspeaker for the upper Donaulände, Regensburger street, Rindermarkt and Ort.
810	Passau	'Ort' partly flooded.

### 3.3 Website of the Bavarian Flood Information Service

The website of the Flood Warning Service (Figure 3.4) gives access to detailed background information and to the latest water level readings and recorded measurements. Maps and charts give a quick overview of the current status 24 hours a day. These sites give access to water level and run-off data from river and lake monitoring stations as well as to measurements provided by precipitation and snow depth monitoring stations.

In a flood event the Flood Bulletin (status report) gives an overview of the flood situation and a forecast of the expected further development. The bulletin is updated several times a day. In their Warnings the state offices for water management provide a detailed description of current and predicted flooding for each one of their county districts that are threatened. In addition reports on past flood events as well as links, addresses and phone numbers of other contact partners can be found on the website ([www.hnd.bayern.de](http://www.hnd.bayern.de)).

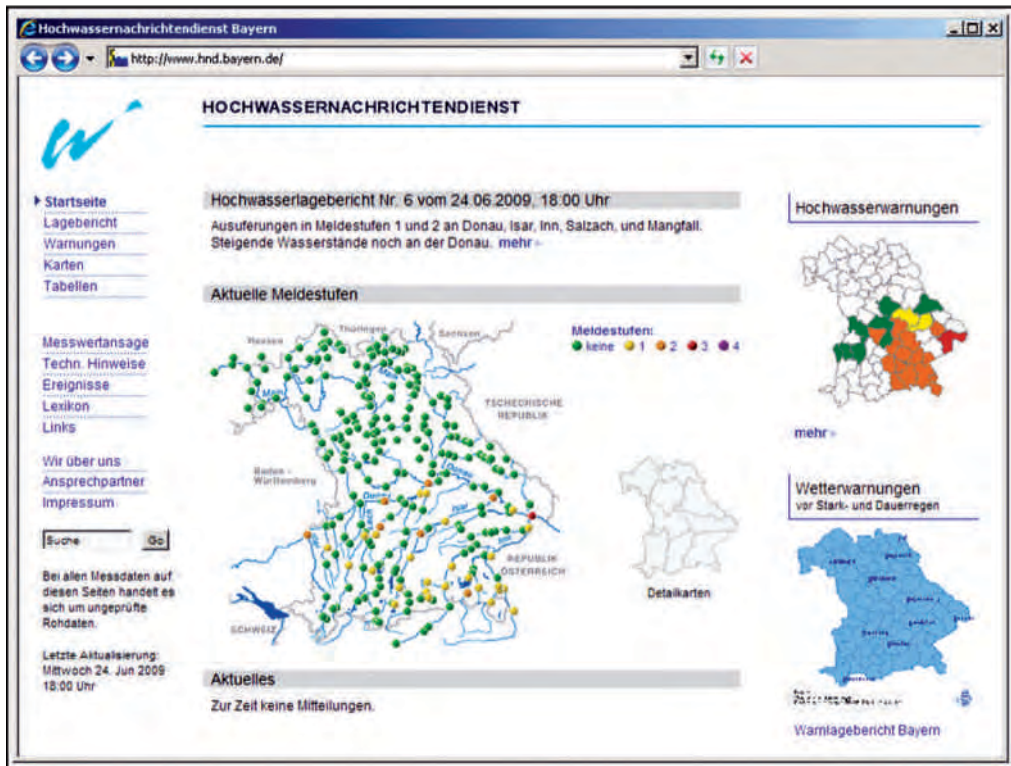


Figure 3.4: Website of the Bavarian Flood Information Service

### Questions

What are the major components of a flood warning system?

What is the goal of a flood warning system?

What are the benefits and costs of flood warning system?



# 4

## LU-C: Real Time Data Acquisition and Monitoring Network

Monitoring of hydro-meteorological conditions in the catchment is of topmost importance for the operational flood warning and forecasting system. The availability of real-time observed data is also important during the flood forecasting stage, as these provide the boundary conditions to the models used. The observed data is used not only to bring the models up-to-date, but also for keeping the models in track with reality through data assimilation. Particularly where lag times are such that desired lead times can be achieved through calculating runoff and routing of observed rainfall and flow, the availability of real-time data is essential (Werner et. al., 2006).

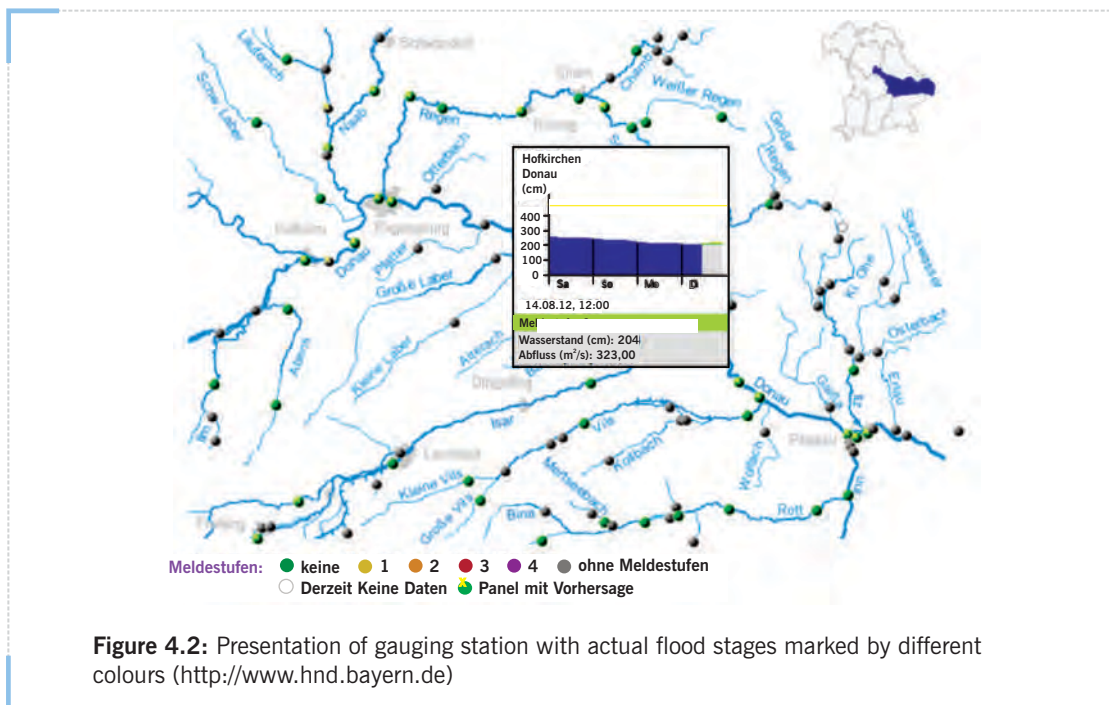


**Figure 4.1:** Real time gauging station (flood stage)  
(<http://www.hnd.bayern.de>)

Most monitoring data is typically provided from telemetry sites, including river gauges and rain gauges. These sites are used for a more general purpose than flood warning alone, providing data also to navigation authorities, water resources planners, irrigation agencies, and others.

For flood warning, the timely availability of the data is obviously an important factor in determining the utility of the data, and also reliability of data transfer is an important aspect. Communication may

simply be through telephone or where reliability of telephone networks is insufficient, through dedicated VHS or UHF radio links. The advances in communication technology have in recent years significantly increased the reliability of data transfer, with off-the-shelf technology such as GSM networks and Internet providing reliable transfer mechanisms (Werner et al. 2006).



**Figure 4.2:** Presentation of gauging station with actual flood stages marked by different colours (<http://www.hnd.bayern.de>)

Although the problems of data transmission are being resolved through advances in communication technology, the reliability of the data itself is an issue that warrants close attention. Validation and checking of all real-time data prior to their use in a forecasting model is important to avoid warnings being issued on the basis of doubtful data.

The data used is mainly that of rainfall accumulations from rain gauges and levels from river gauging stations. For upstream boundaries, water levels are typically transformed into discharge through stage discharge relationships. Particularly in severe floods, these stage-discharge relationships may contain a significant degree of error, and the reliability of these relationships at high flows should be carefully assessed. For catchment rainfall estimates derived from rain gauges, the problem of scale arises, as the point measurements must be up-scaled to catchment rainfall estimates (Werner et al. 2006).



**Figure 4.3:** Real-time precipitation-station ([www.hnd.bayern.de](http://www.hnd.bayern.de))

The use of weather radar partially solves the problem of spatial coverage of rainfall estimates. Weather radar provides a spatial estimate of precipitation as inferred through the radar reflectivity of the rainfall, and a reliable relationship between reflectivity and rainfall rate must be applied. Unfortunately, no unique relationship is available. In addition, there are a number of physical factors influencing uncertainties in radar derived rainfall estimates. These are not only due to atmospheric distortions such as the melting layer, but also due to, for example, radar beam shielding in mountainous areas. In practice, integration of rain gauge data and radar rainfall estimates can be combined to provide more reliable estimates of distribution and volume of observed rainfall (Werner et. al., 2006).

#### Important points to remember about gauge networks

- Accurate, reliable, and timely gauge data is essential to the success of a flood warning system.
- The establishment of a hydro-meteorological network for flood support can often be an exercise in integrating and automating already existing networks.
- Tipping-bucket rain gauges tend to underestimate precipitation during periods of intense rainfall, but they are less expensive than weighing gauges.
- All gauges have a maintenance cost, although the cost associated with tipping bucket gauges is less than that associated with weighing gauges.

(National Weather Service, 2010)



### Important points to remember about gauge networks

- Robust communication between the observation networks and the forecasting centre are the key to the success of a flood warning system. In adopting a communication system for a gauge installation, one consideration has to be its reliability under severe environmental conditions.
- Alternate communication paths for data collection and product dissemination are needed within a Meteorological and Hydrological Service to ensure 24/7 operations.

(National Weather Service, 2010)

## 4.1 Satellite-based estimates of rainfall and soil moisture

The finest resolution of satellite-based precipitation estimates is currently around 4 km, which is about 3 times coarser than even the largest range gates on most radar.

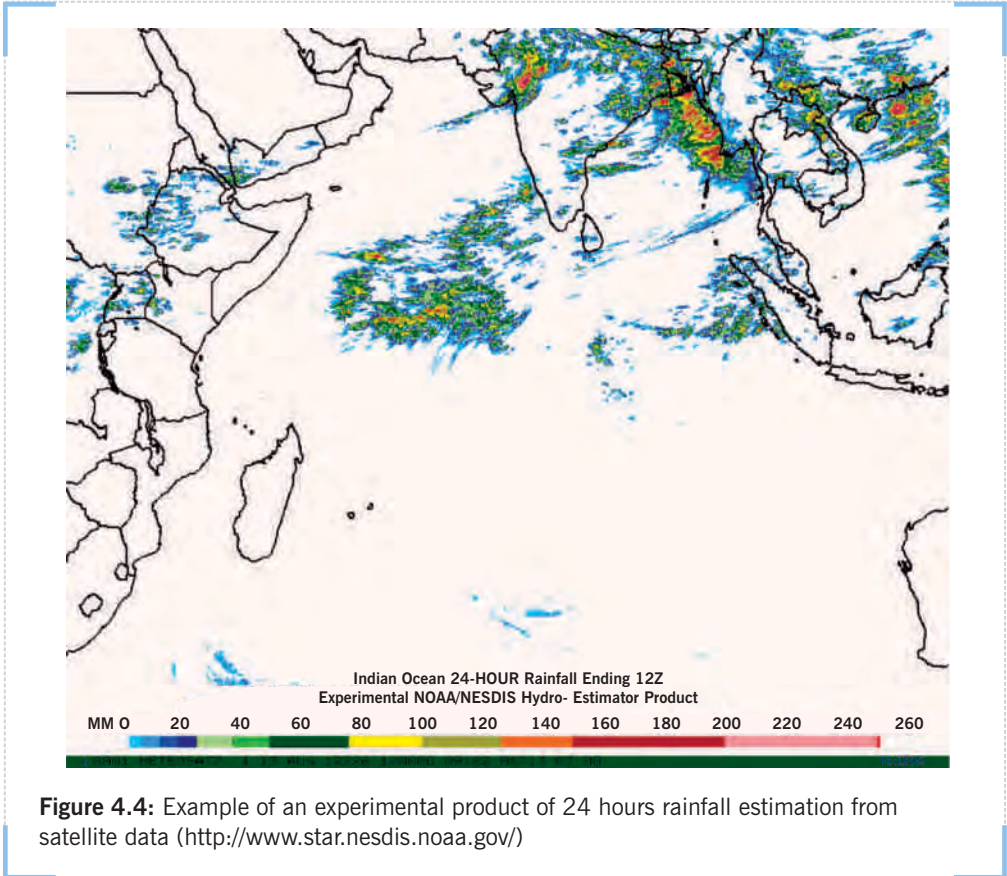
Another limitation of precipitation rates estimations by geostationary satellite is that infrared cloud surface temperatures are used only as a proxy for a cloud that is producing precipitation and is not a measure of the precipitation itself. Thus, the algorithms sometimes mis diagnose low to medium level clouds because of their higher temperature as not producing precipitation even when they are. Furthermore the falling rain can be drifted by winds and hits a different location than assumed by the analysis of the satellite data. For this reasons, the used algorithms are best suited for deep convection situations in the tropics and mid-latitudes, especially when the environmental winds do not vary much with height.

Products that blend microwave precipitation rates from polar orbiting satellites with geostationary cloud-top temperature information are usually more accurate than a simple geostationary estimate because they are based on direct observation of emissions from precipitation hydrometeors. But, their reduced spatial and temporal coverage means that true microwave rain rate products for any given location become available only every 3 to 4 hours on average, which sometimes limits its usefulness for detecting the severity and timing of flash flood type situations.

### Important points to remember about satellite data

- Satellite estimates of precipitation can be partially corrected by simultaneously measured rain gauge to get “ground truth” data.
- Gridded rainfall estimates are the primary source of precipitation information for areas that lack radar networks and networks of rain gauges.
- Rainfall estimates can be computed for the entire planet by making use of both Polar Orbiting and Geostationary satellites.

(National Weather Service, 2010)



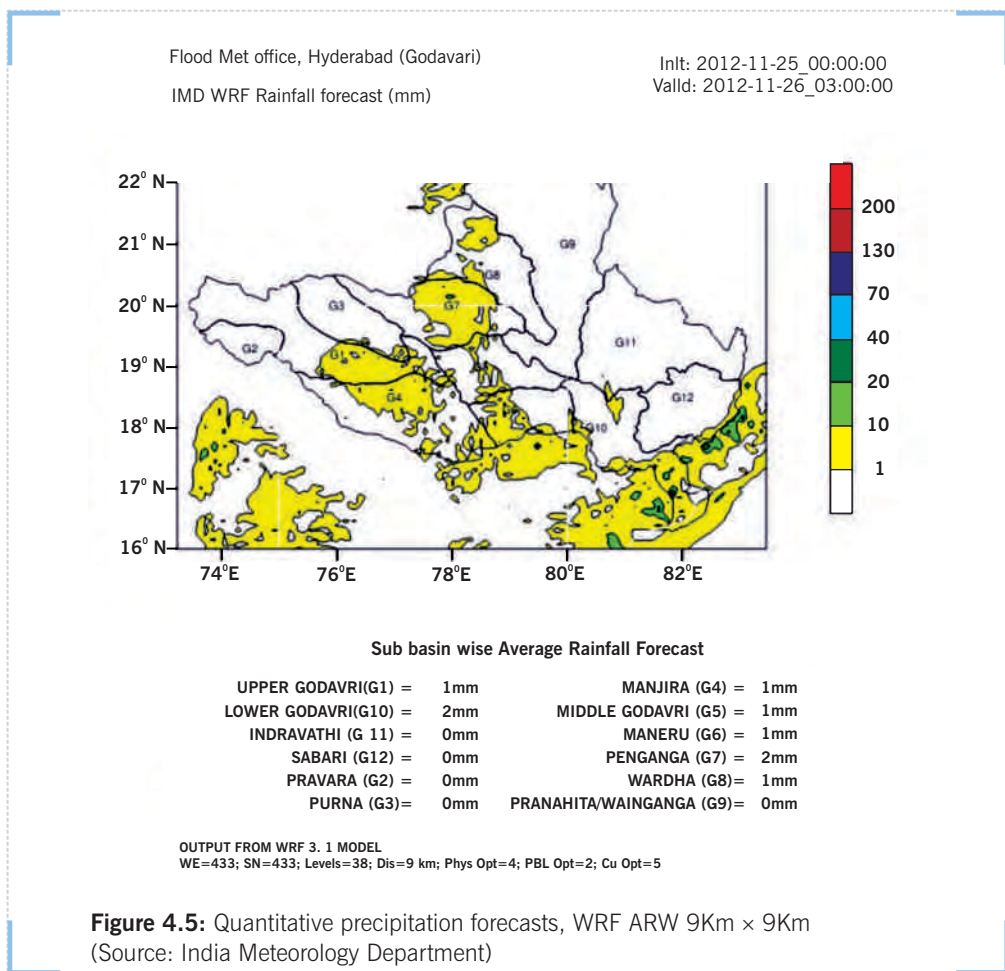
**Figure 4.4:** Example of an experimental product of 24 hours rainfall estimation from satellite data (<http://www.star.nesdis.noaa.gov/>)

Satellite Precipitation Estimation Resources (MetEd, 2011):

- Virtual Institute for Satellite Integration Training (VISIT) links and tutorials [http://rammb.cira.colostate.edu/training/visit/links\\_and\\_tutorials/](http://rammb.cira.colostate.edu/training/visit/links_and_tutorials/)
- CMORPH: [http://www.cpc.noaa.gov/products/janowiak/cmorph\\_description.html](http://www.cpc.noaa.gov/products/janowiak/cmorph_description.html)
- HYDRO-ESTIMATOR: <http://www.star.nesdis.noaa.gov/smcd/emb/ff/HydroEst.php>
- EUMETSAT MPE: <http://oiswww.eumetsat.org/IPPS/html/MSG/PRODUCTS/MPE/>
- PERSIANN: [http://chrs.web.uci.edu/research/satellite\\_precipitation/activities00.html](http://chrs.web.uci.edu/research/satellite_precipitation/activities00.html)
- SCaMPR: <http://www.star.nesdis.noaa.gov/smcd/emb/ff/SCaMPR.php>

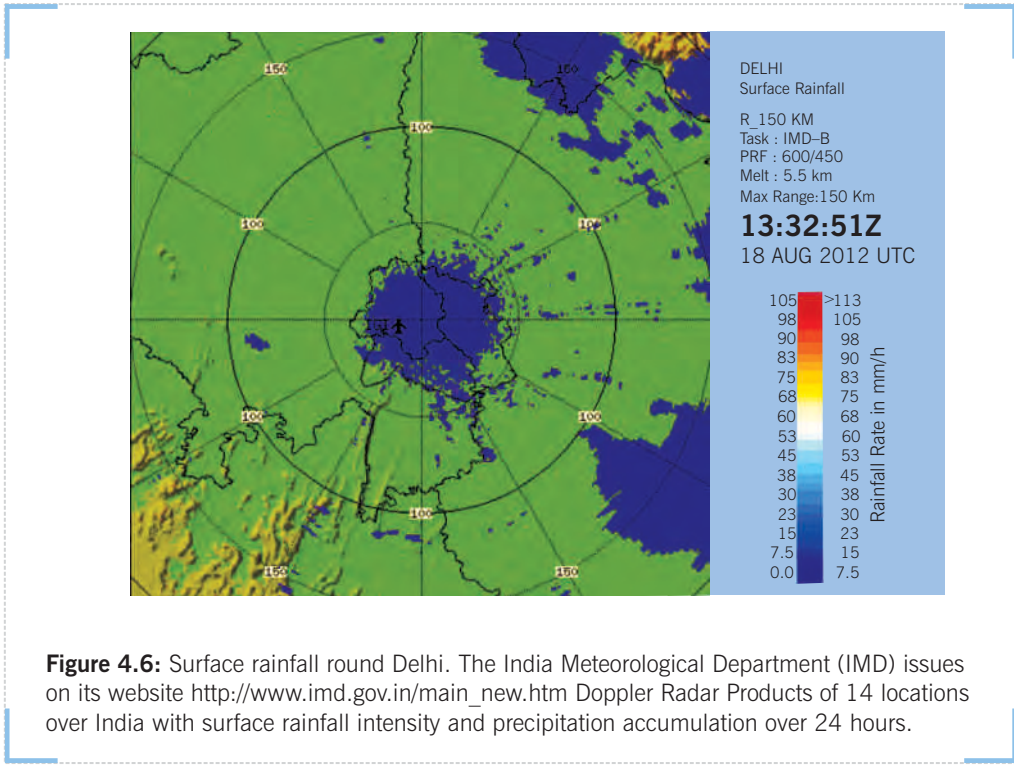
## 4.2 Flood-related weather observation in India

The real-time monitoring and statistical analysis of district wise daily rainfall is one of the important functions of the Hydro Meteorological Division of IMD at New Delhi. Based on the real time daily rainfall data, weekly district wise, sub-division wise and state wise rainfall distribution summaries are prepared regularly by the Rainfall Monitoring Unit. Maps showing weekly and cumulative rainfall figures in 36 meteorological subdivisions of the country are prepared. Hourly rainfall data in real time are available for numerous stations via the IMD website (<http://www.imd.gov.in/section/hydro/QPF/WRF/>).



Flood Meteorological Offices (FMOs) have been set up by IMD at ten locations viz., Agra, Ahmedabad, Asansol, Bhubaneshwar, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi and Patna. During the flood season, FMOs provide valuable meteorological support to the Central Water Commission for issuing flood warnings in respect of the following rivers (from <http://www.imd.gov.in/services/others/hydrometeorology-flood.htm>):

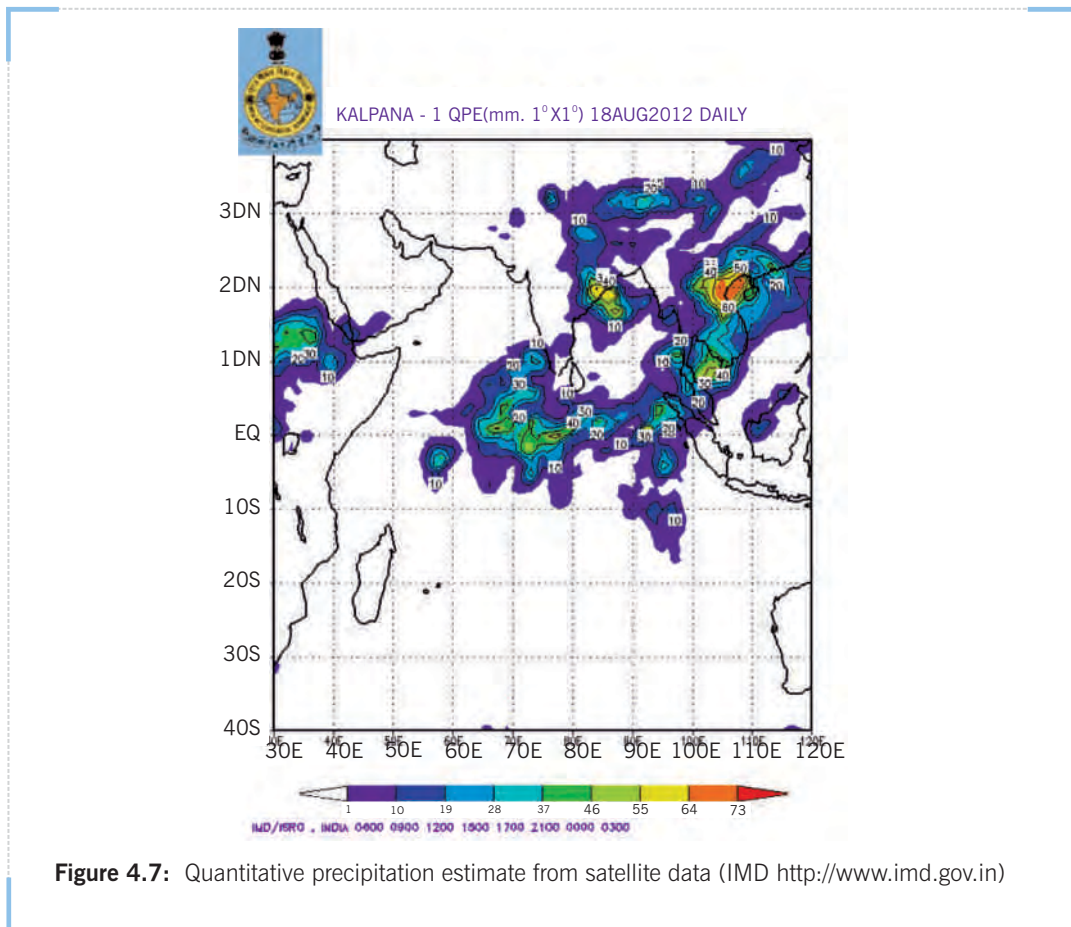
- Agra: Lower Yamuna and Betwa
- Ahmedabad: Narmada, Tapi, Mahi, Sabarmati, Banas and Deman Ganga
- Asansol: Ajay, Mayurakshi and Kangsabati
- Bhubaneshwar: Mahanadi, Brahmani, Baiterini, Bruhaba-lang, Subernarekha, Rushkulya and Vansdhara
- Guwahati: Brahmaputra and Barak
- Hyderabad: Godawari and Krishna



**Figure 4.6:** Surface rainfall round Delhi. The India Meteorological Department (IMD) issues on its website [http://www.imd.gov.in/main\\_new.htm](http://www.imd.gov.in/main_new.htm) Doppler Radar Products of 14 locations over India with surface rainfall intensity and precipitation accumulation over 24 hours.

- Jalpaiguri: Teesta
- Lucknow: Ganga, Ramganga, Gomti, Sai, Rapti Ghagra and Samda
- New Delhi: Upper Yamuna, Lower Yamuna, Sahibi
- Patna: Kosi, Mahananda, Baghmata, Kamla, Gandak, Buri Gandak, North Koel, Kanhar, Pun Pun and Upper Sone.

For these river basins IMD also calculates quantitative precipitation forecasts based on the WRF model over 3 days (see chapter 5).



# 5

## LU-D:

# Meteorological Forecasts

Dependent from the lead time of the forecast there are:

- Now-casts for a few hours,
- Short-range forecasts between 4 and 48 hours
- Medium-range forecasts between 2 and 10 days and
- Long-range or seasonal forecasts for 10 to 365 days.

Now-casts are based on the extrapolation of observations in time. Ground measurements of precipitation for instance can be forecasted by using time series analysis techniques, stochastic models or artificial neural networks. Animated pictures of observed radar rainfall often show a movement of rainfall fields or frontal rains. This movement can be forecasted for the next few hours by keeping the velocity and the direction of the propagation. The German weather service publishes a two hour now-cast based on this method.

For longer lead times, improvements of skill levels in numerical weather prediction models (NWP) made it more feasible to integrate weather prediction with flood forecasting systems. Numerical weather prediction models are available either as global models or as regional models (also known as limited-area models, or LAMS) for a particular section of the atmosphere. The latter are of a higher resolution and are nested in the global models (Werner et al., 2006).

Examples of global models are the European Centre for Medium-Range Weather Forecasting (ECMWF) deterministic and ensemble prediction systems, the German Weather Service global model (GME) or the Global Forecast System (GFS) run by NOAA. Many national meteorological agencies operate limited area models, for example, the ARPS University of Oklahoma, COSMO-DE (German Weather Service), HIRLAM (Danish Meteorological Institute) or the National Centre for Medium Range Weather Forecasting (NCMRWF) in India.

The numerical weather forecast products are the most important source for analysing the flood risk over the next 2 to 5 days.

Obtaining a quantitative precipitation forecast (QPF) at appropriate spatial and temporal scales is not an easy task as rainfall is one of the most difficult to forecast element of the hydrological cycle. This is especially true in India with the indeterminacy of monsoon rains.

#### Questions

- What kinds of numerical weather forecast products exist?
- Who does it?
- From whom can I get it?
- What does it cost?

## 5.1 German Weather Service (DWD)

With a grid length of 30 km on 60 vertical layers, the global model GME calculates at a total of 39 million grid points the temporal evolution of weather parameters, such as air pressure, wind, water vapour, clouds and precipitation for up to seven days in advance. For Europe the regional model COSMO-EU (formerly known as LME), with a grid length of 7 km on 40 layers, uses a total of 17.5 million grid points to provide detailed weather forecasts for up to three days in advance. During computation the COSMO-EU receives the GME forecasts as lateral boundary values. The high resolution model COSMO-DE (formerly known as LMK), with a grid length of only 2.8 km and 50 layers at a total of 9.7 million grid points, has been delivering eighteen-hour forecasts for Germany 8 times per day, in particular for the warning of dangerous weather systems such as storms and thunderstorms. The lateral boundary values are derived from COSMO-EU forecasts.

The DWD provides the High Resolution Model (HRM) for use at other Meteorological Services, especially in developing and newly industrialised countries, such as Vietnam, the Philippines, or Kenya. GME forecast data are sent to these Meteorological Services twice a day via the Internet as lateral boundary values for calculations with the HRM (<http://www.met.gov.om/hrm/index.php>).

## 5.2 Numerical weather prediction in India

The India Meteorological Department publishes on its website (<http://www.imd.gov.in>) quantitative precipitation forecasts based on the WRF model with a grid length of 9 km and a lead time of 3 days. In addition there are basin rainfall estimate for different river basins in the area.

India Meteorological Department (IMD) has a mandate to issue short-range forecasts (validity of 2-3 days) and long range seasonal forecast. National Centre for Medium Range Weather Forecasting (NCMRWF) has the mandate for medium range (validity 4-10 days) forecasting. Many of the Numerical Models such as the Limited Area Model (LAM) and 5th Generation Meso-Scale Model (MM5) are being used for short range weather forecasts. IMD's long range forecast is based on statistical model that uses a number of global parameters called predictors which have high correlation with monsoon rainfall. At present, IMD uses 8 to 10 parameter models for long range forecast. In view of potential of numerical models, IMD has adopted an experimental prediction system based on numerical models. For this purpose, IMD under a collaborative research programme with Indian Institute of Science, Bangalore has adopted a numerical model developed at the Experimental Climate Prediction Centre (ECPC), Scripps Institute of Oceanography, USA.

The model resolution and the accuracy have limitations vis-à-vis the more advanced countries because of the inadequate infrastructure such as observational network, computing capacity and human resources. Upgrade of observational network, enhancement of computing facility for running high resolution numerical weather prediction models and improvement of communication network are required to meet the present requirements and to achieve global standards in weather forecasting ([http://www.dst.gov.in/admin\\_finance/sq288.htm](http://www.dst.gov.in/admin_finance/sq288.htm), 2006).

In India the National Centre for Medium Range Weather Forecasting (NCMRWF, <http://www.ncmrwf.gov.in/>) develops advanced numerical weather prediction systems, with increased reliability and accuracy over India. The National Centre for Medium Range Weather Forecasting (NCMRWF) makes available its various operational forecast products from its Global Forecast System at various resolutions on its ftp site with free access. These data will be retained in the ftp site only for a limited period. It is expected that the user community will acknowledge the data source used for the research in its publications and intimate us about the usage details which will motivate us to continue with this service and possibly inform the potential users regarding any changes in the data supply in advance.



GEFS : Rainfall (cm/day), Ens Mean  
 24-hr Forecast valid for 00Z18AUG2012 (IC = 00Z17AUG2012)

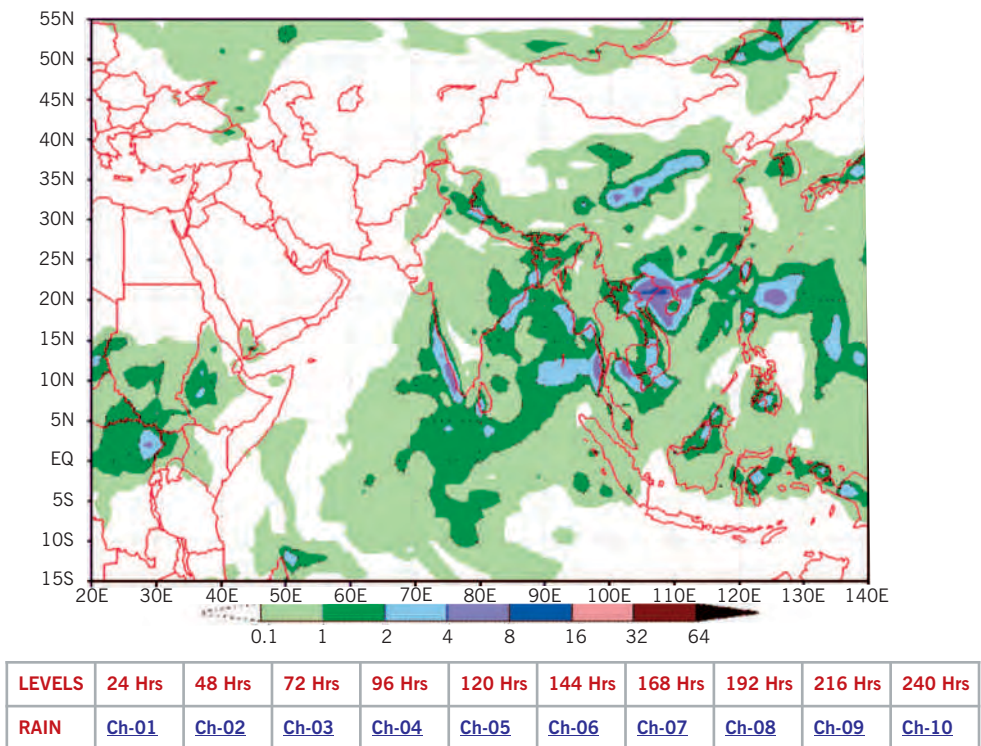


Figure 5.1: Example of 24-hr precipitation forecast (<http://www.ncmrwf.gov.in/>)

# 6

## LU-E: Flood Forecast System

The basic elements of the flood forecast system are:

- real time data acquisition,
- hydrologic and hydraulic models,
- update of the forecast and data assimilation.

Real time data acquisition delivers the necessary input data to the hydrologic and hydraulic models like precipitation data or upstream discharge data. Hydrologic and hydraulic models simulate hydrologic flood processes and calculate forecasts. A wide range of hydrologic and hydraulic modelling approaches may be applied where models take information on the current and past states of the system, and forecasts are made for the desired lead time as a function of boundary inputs on the system. Where necessary, forecasts of meteorological conditions are required to allow issue of warnings at sufficient lead time. Generally, these forecasts are sourced from meteorological services, and must be integrated within the flood forecasting system. Through the process of data assimilation and updating, simulated data are combined with real-time data to provide a more accurate forecast and to equal the last observation point to the first forecast point. The use of an updating or data assimilation technique is an important aspect of applying models in real time (Werner et al., 2006).

Accuracy, reliability and timeliness are basic requirements in operation of the forecast system. Real time operational forecast is very much a time critical exercise (Szöllösi-Nagy, A.,2009). Simplicity of the methods used to process the input data and to calculate the forecasts is a key requirement. Robustness of the system components i.e. the possibility to handle with missing input data in real time is another main pillar.

Dependent from the lead time of the forecast we distinguish:

- Now-casts for a few hours,
- Short-range forecasts between 4 and 48 hours,
- Medium-range forecasts between 2 and 10 days, and
- Long-range or seasonal forecasts for 10 to 365 days.

The origin of these types is the weather forecast and it works for the flood forecast too. Long-range forecasts are of little practical use in flood warning. Medium-range flood forecasts are based on medium-range weather forecasts with the same degree of reliability. There may be travel times of the flood wave of several days in large rivers. In this case even medium range flood forecasts can be based on measured upstream gauging stations with a high degree of reliability.

With forecast models we get measures like water level and discharge usually at a gauging station. Mostly, the expected flood peak is of highest interest. But there are other quantities, like

- full hydrograph (i.e. to estimate the expected inflow volume to a reservoir),
- probability of overtopping certain critical flood stages (i.e. to manage flood protection response),
- duration of overtopping a critical flood stage, and
- forecast of the expected flooded area.

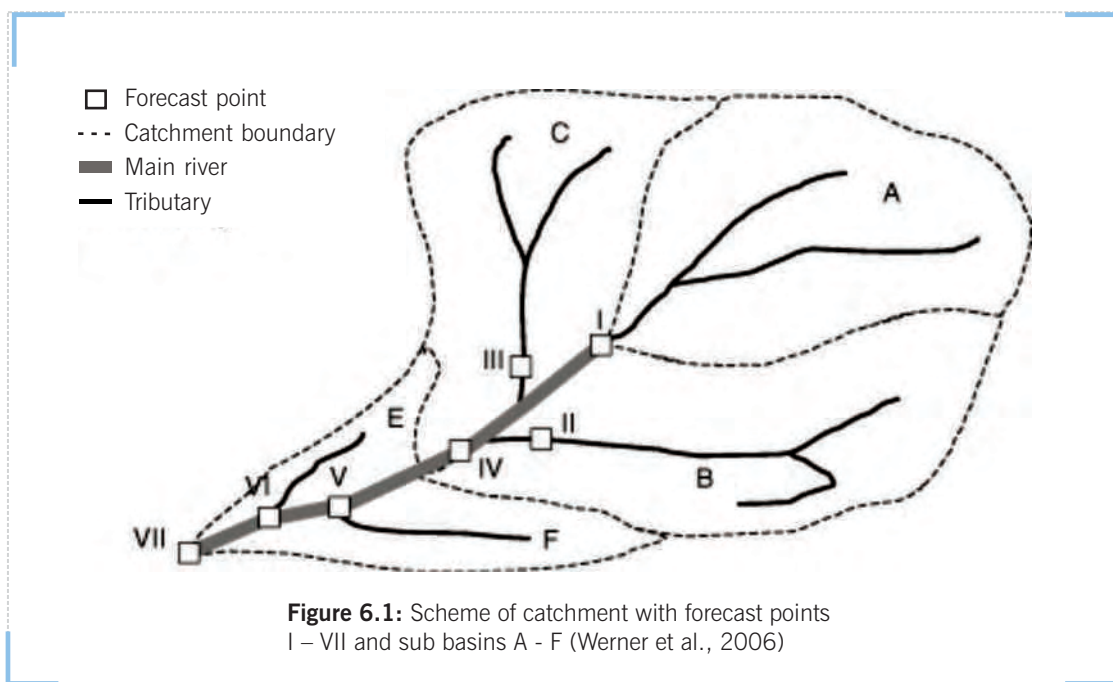
## 6.1 Hydrologic response time and lead time of the forecast

The difference between the forecast of a meteorological event like precipitation and the hydrological event like a flood peak is the dependence of the forecast-lead time from the catchment size.

Preliminary considerations about the flood drainage behaviour of the catchment at the forecast point are essential to decide which type of forecast models and input data are necessary to get a reliable forecast. In particular, observations of the travel time of the flood peak, the time to peak and the time of runoff concentration in the catchment provide information about reachable forecast lead times specially without extension by less accurate precipitation forecasts.

There are three different types (simplified approach from Werner et al. 2006):

- Type 1: The time the water needs to flow through the river channel is greater than the time water needs to flow as runoff over land. The flood routing process dominates form and volume of the flood wave. Forecasts can be based on upstream gauging measurements.
- Type 2: The time the water flows over land to the river is greater than the time the water flows through the river channel, concentration of runoff dominates form and volume of the flood hydrograph. The possible lead time is connected to the time to peak or the time between the rainfall event and the flood peak. Forecasts are based on precipitation and/or snow melt measurements.
- Type 3: Desired lead time is greater than the time the water needs to flow over the land and through the river channel. It means that the response time of the system to the rain or to the snow melt is shorter than the desired lead time of the forecast and we need a forecast of rain or snow melt to get a sufficient lead time. This type is found in small catchments and flash flood situations.



Exercise: Assign type 1, 2 or 3 to the forecast point I, II, III, IV, V, VI and VII in Figure 6.1

**One example should clarify this issue (for type 1):**

Consider the Nile River coming from the highlands of Ethiopia: In the time of heavy rains there, large amounts of water start to flow, but on the way through Egypt with a desert-like condition, no additional water reaches the Nile and forecast lead times depends only from the travel time of the peak along the river. Here the challenge is modelling the loss of water by irrigation.

**Questions**

What are the three main components of a flood forecast system?

What is the hydrological response time and how it is related to the lead time of the forecast?

What are three basic requirements to a forecast system?

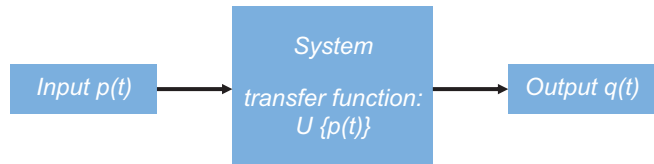
What are the four main lead time horizons?

# 7

## LU-F: Hydrologic and Hydraulic Models

The building of models in hydrology makes use of methods of applied system analysis. System analysis deals with the analysis of complex systems. The objective of this analysis is the construction of a model as a simplified and abstract image of the real system.

The models in hydrology are based on the physical law of mass conservation (continuity). The sum of changes in input and output of the system has to be the sum of changes in the state of the system at a certain time step. Inputs to a system are transferred to outputs and may be calculated by a mathematical transfer function below.



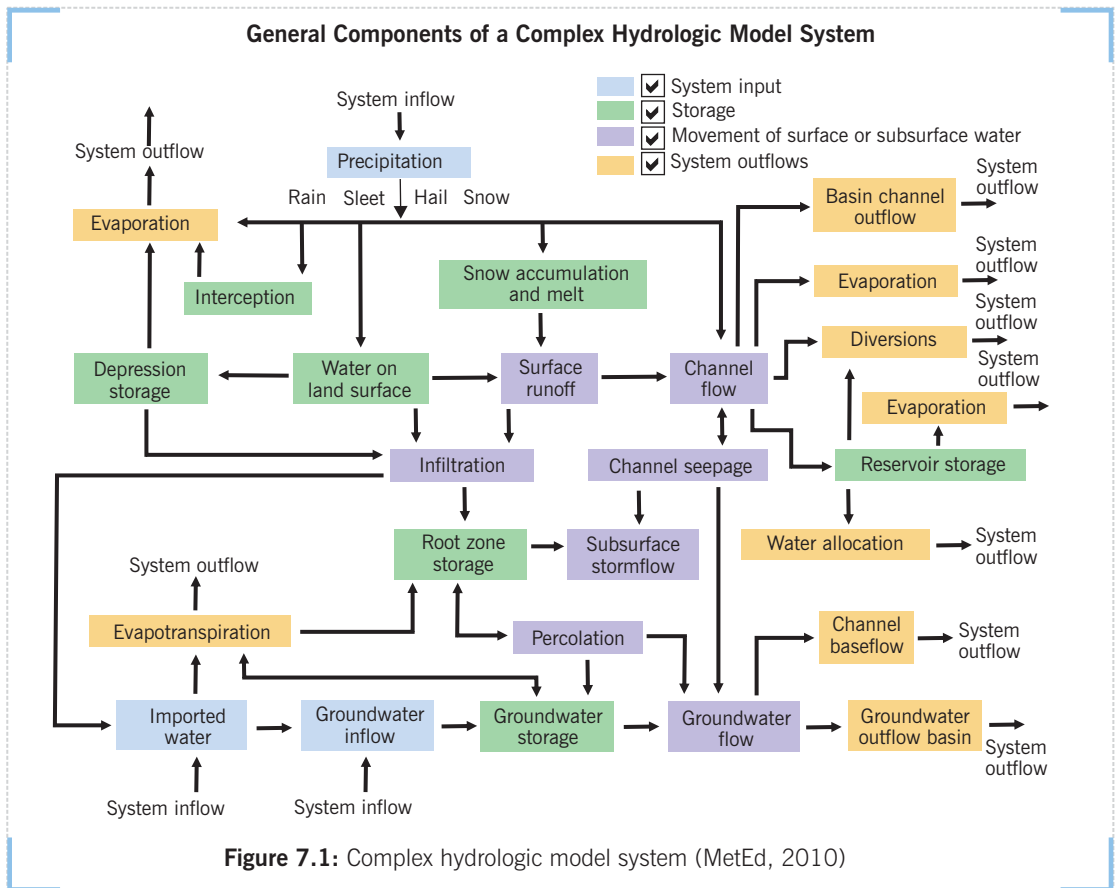
Input – Output – System with  $q(t) = U \{p(t)\}$ , where  $U$  is the system- or transfer function

The transfer function describes the transformation of the input (i.e. precipitation) to the output (i.e. runoff). A simple case of a transfer function is a linear regression function as shown in Figure 7.2.

The typical system in hydrologic forecasts may be a catchment with input of precipitation and output of runoff or a channel reach with inflow and outflow.

The system can be composed of different components like the complex hydrologic model system in Figure 7.1.

There are different models described briefly in Table 7.1.



## 7.1 Black box model

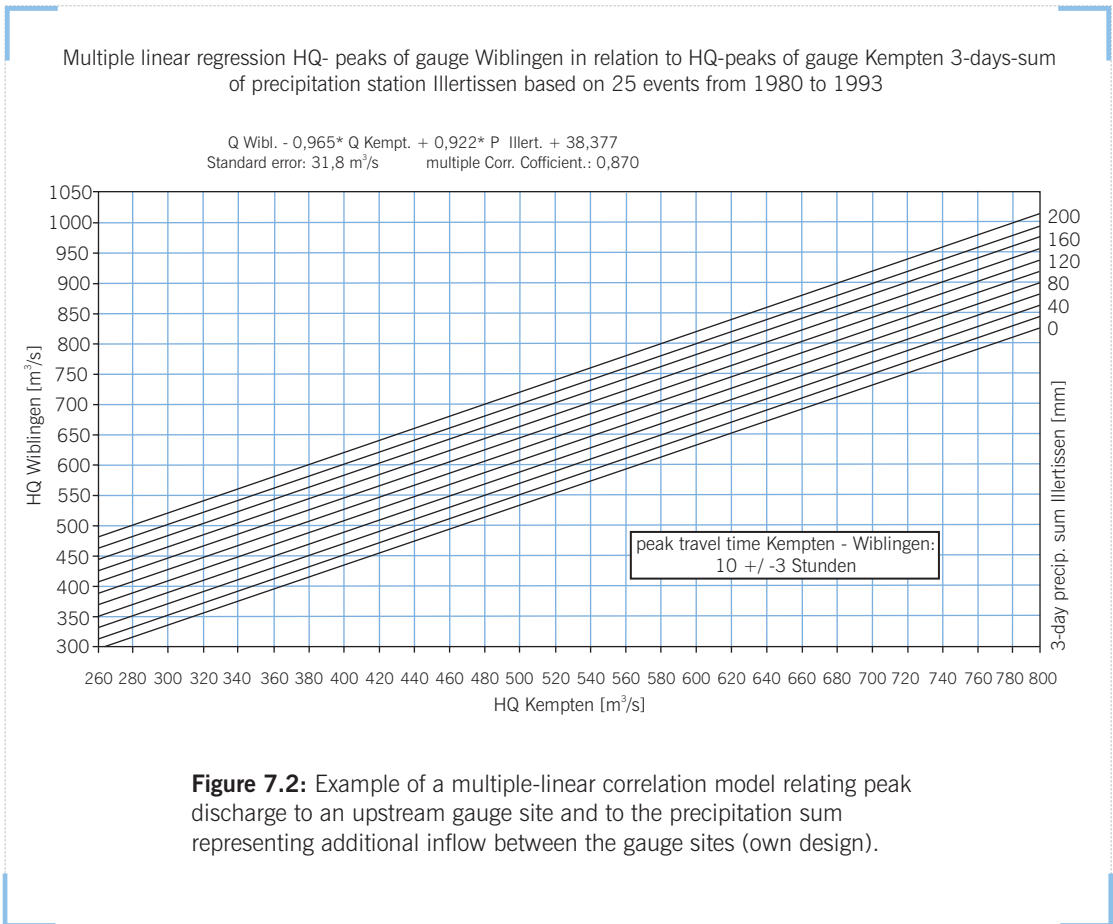
In a black box model input and output values are determined only by measuring data and expressed in mathematical algorithms. The transfer function is determined without any knowledge of the internal working of the system only by its input and output measurements. Different models of this type can be distinguished by the type of the transfer function. These can be correlation functions (Figure 7.2), filtering techniques known from signal processing and time series analysis or simple conceptual models like the unit hydrograph.

Methods of data mining, artificial neural networks or genetic programming are further methods to formulate the transfer function without an explicit physical description of the system.

The main attraction of black box model is that the model structure is identified using available data only. This leads to efficiently parameterized model structures. These are also relatively simple to implement and computationally very efficient.

However the lead time is limited to a time-lag between input event and output event. By applying the transfer function to the flood routing process the lead time corresponds to the travel time of the flood wave. Applied to the process of runoff concentration it is in the order of the response time of the catchment to precipitation.

Because there is no physical description of the system a change in the physical properties leads to invalid results and the historic database can no longer be used to identify the transfer function.



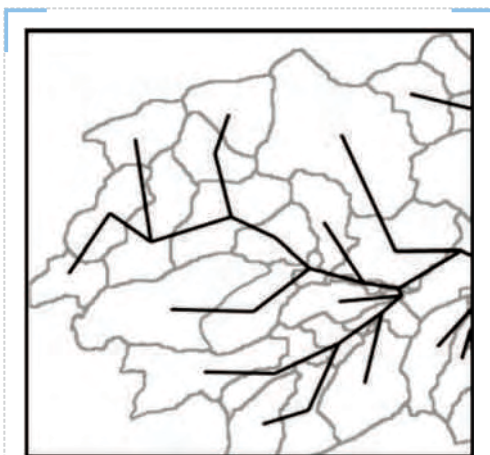
**Figure 7.2:** Example of a multiple-linear correlation model relating peak discharge to an upstream gauge site and to the precipitation sum representing additional inflow between the gauge sites (own design).



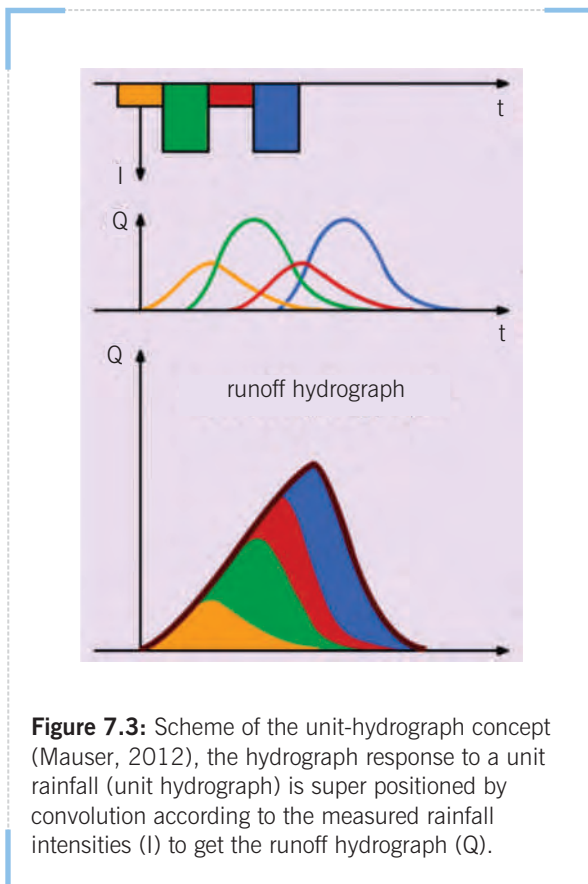
## 7.2 Distributed models

Computer technology made it possible to apply more physically based and spatially distributed models in flood forecast. In most forecasting centres in Europe this type of models are used.

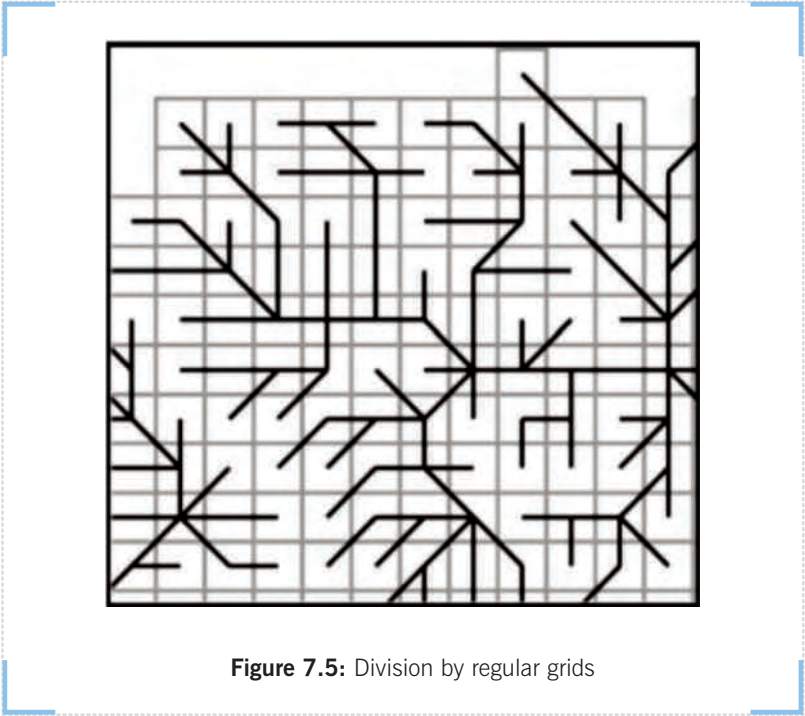
In distributed models the catchment is divided in smaller subunits. The subdivision may be done by a regular grid of cells or by small sub catchments using geographical information system. The size of the grids or sub basins varies with the size of the spatial scale of the processes, the scale of available geographic maps and the computational possibilities. Most common is a grid size of 1x1km. For very large catchments with areas of more than 50000 km<sup>2</sup> often a grid size of 4x4 or 5x5 km are used.



**Figure 7.4:** Division by sub-basins



**Figure 7.3:** Scheme of the unit-hydrograph concept (Mauser, 2012), the hydrograph response to a unit rainfall (unit hydrograph) is super positioned by convolution according to the measured rainfall intensities (I) to get the runoff hydrograph (Q).



For each cell or sub basin the vertical fluxes and storage of water (artificial and manmade ponds and tanks, lakes, storage in snow compaction, snow melt, interception, depression storage, infiltration, percolation, soil storage, groundwater recharge, evaporation and transpiration) are calculated depending on the land use and properties of soil. Movement of surface flow and subsurface flow are calculated either by simplified concepts of translation and linear storage, the concept of parallel linear cascades or by the more physically based kinematic wave method for surface flow and the Richards equation for soil water movement.

Regarding the vertical water fluxes there are two types of models. First, the event based models considers only the most dominant processes during flood (rainfall and summarized water losses due to interception and infiltration) in a very simple concept. Water losses by evapo-transpiration are neglected. At the beginning of the event a factor can be applied to the rate of direct runoff volume depending on the water saturation state of the catchment.

Second the water balance model accounts for all processes of the water cycle over land including evapo-transpiration and soil moisture accounting (Figure 7.1).

**Table 7.1:** Model types and characteristics

Model Type	Hydrologic Concepts and processes	Input Data	Geographical Data	Advantages	Disadvantages	Examples (see box 1 below for details)
Block Model	Rainfall – Runoff in flood situation or flood routing	Precipitation or upstream flow data	No	Simple to implement and to calculate	Limited lead time, valid only in observed range used for calibration	Regression, filter (Wiener, Kalman), ARIMA, ARMAX
Distributed event based model	Direct runoff, rainfall loss (snow melt)	Precipitation, (Air temperature and wind speed for snow melt)	Geographical data of sub basins or grids and channels	More physically based and spatially distributed	Estimation of losses to get the volume of direct runoff, less physically based	FGMOD NAM
Distributed water balance model	Interception, Infiltration, Percolation, Runoff, evapotranspiration, components of surface, soil and groundwater	Precipitation, potential evaporation, wind, air pressure, vapour pressure	Geographical data of sub basins or grids, channels, soil, land use, digital elevation model	More physically based and spatially distributed, better estimation of saturation state in the basin	Big number of input variables, high skill for calibration	HBV HEC-HMS TOPKAPI LARSIM SHE NWSRFS LISFLOOD
Hydraulic 1-D Model	Water movement and water depth in the floodplain	Water level and/or discharge	Length, slope and cross section of channels and floodplain	Physically based, short computing times		HEC-RAS MIKE 11 SOBEK
Hydraulic 2-D Model	Water movement and water depth in the floodplain, backwater effects	Water level and/or discharge	Digital elevation model of the floodplain in high resolution	Physically based, complex flow situation, modelling flood extent	Long computing times prevent application in flood forecast	SOBEK MIKE 21

### Box 1

FGMOD is part of the LARSIM model, where it is possible to switch between event-based FGMOD mode and the water balance mode of LARSIM, used in forecast centres of Germany, non-commercial product.

NAM by Danish Hydraulic Institute, the rainfall-runoff model comes with the hydrodynamic Model MIKE 11, commercial product.

HBV-96 by Swedish Meteorological and Hydrological Institute used in many forecast centres in Sweden, Netherlands, Germany, Austria and also in India and in other countries, non-commercial product.  
<http://www.smhi.se/sgn0106/if/hydrologi/hbv.htm>.

HEC-HMS by Hydrologic Engineering Centre of the U.S. Army Corps of Engineers, the Hydrologic Modelling System used mainly in the U.S., non-commercial product.

TOPKAPI by the University of Bologna, Italy, used in the forecast centre for the Po River in Italy, non-commercial product.

LARSIM (Large Area Simulation Model) based on FGMOD by the University of Hannover (Germany), used in forecast centres in Germany, France and Austria, non-commercial product.

SHE (Système Hydrologique Européen) was originally developed by the Danish Hydraulic Institute (DHI), SOGREAH (France) and the Institute of Hydrology (UK), non-commercial product but as MIKE-SHE in connection with MIKE 11, commercial product by DHI

US National Weather Service US National Weather Service River Forecast System NWSRFS River Forecast System by the U.S. National Weather Service uses different model components, i.e. SAC-SMA (Sacramento Soil Moisture Accounting Model) used in forecast centres of the National Weather Service, non-commercial product.

LISFLOOD by Joint Research Centre of the European Commission, used by EFAS (European Flood Alert System), non-commercial product, <http://floods.jrc.ec.europa.eu/lisflood-model>.

HEC-RAS by Hydrologic Engineering Centre of the U.S. Army Corps of Engineers, 1D-hydrodynamic modelling of open channel flow, used in many countries, non-commercial product.

MIKE 11 and MIKE 21 by Danish Hydraulic Institute, commercial product. MIKE 11 offers a unique possibility to simulate catchment runoff in many ways, from simple empirical rainfall-runoff methods to complex fully distributed process-based oriented modelling with MIKE SHE and is used extensively in India by NIH, CWC etc. particularly under Hydrology Project –II by Ministry of Water Resources and also by several academic and research institutions.

SOBEK by Delft Hydraulics and Deltares, used in forecast centres of Germany, Netherlands and others, commercial product.

### 7.3 The LARSIM model as an example for a distributed conceptual model

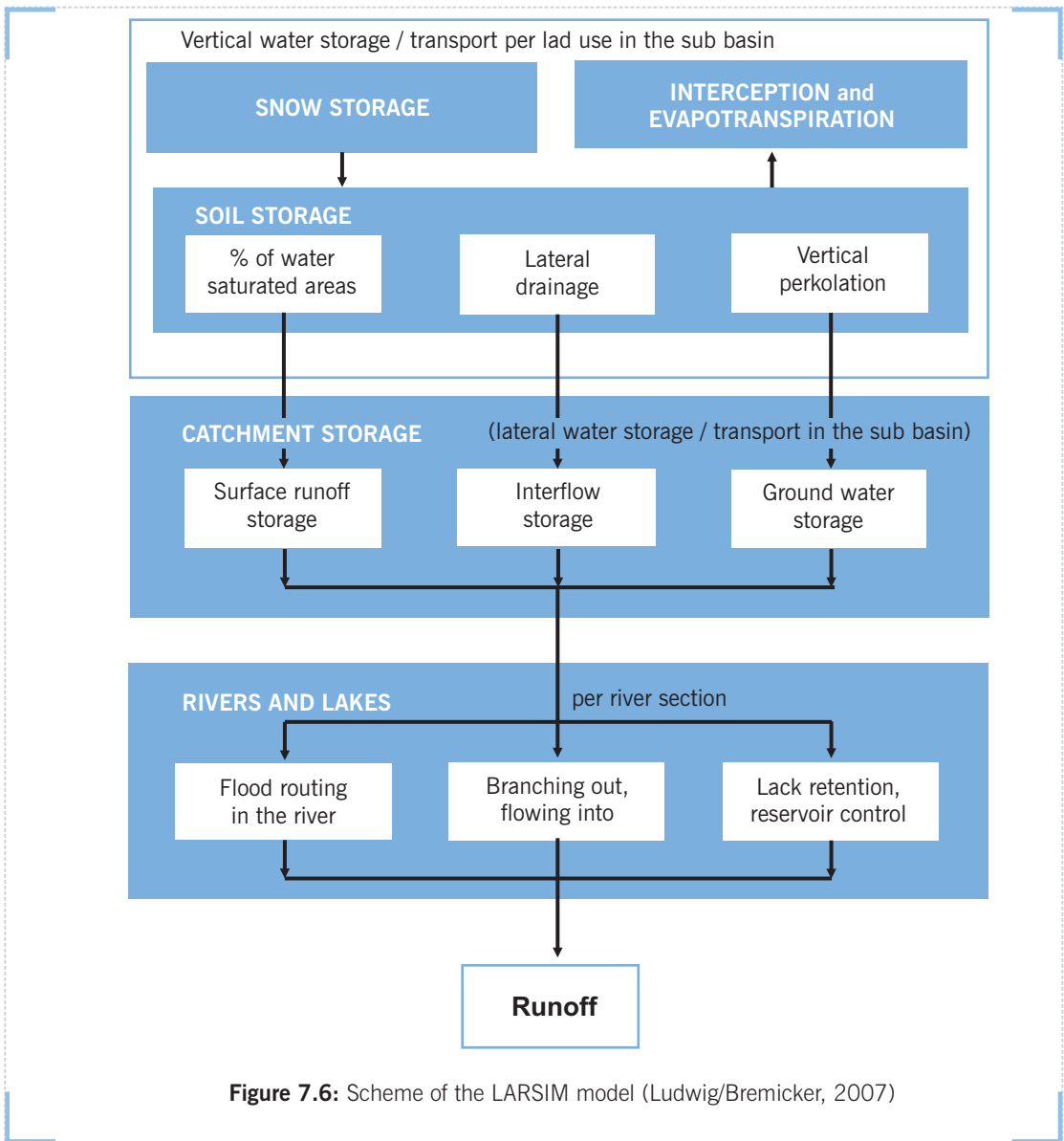


Figure 7.6: Scheme of the LARSIM model (Ludwig/Bremicker, 2007)

LARSIM includes mathematical computation procedures to continuously describe and quantify the spatial and temporal distribution of the water balance's essential land phase components like precipitation, evapo-transpiration, infiltration, water storage and runoff. The water balance model LARSIM (Large Area Runoff Simulation Model) is a so called conceptual model, i.e. the complex processes in the natural system are reproduced by simplified model concepts.

Because rain is the input into the model it shouldn't matter if the rain is caused by rain types of temperate climate or the monsoon type. Therefore the LARSIM model can be used in India (as well as the other hydrologic models mentioned in this chapter).

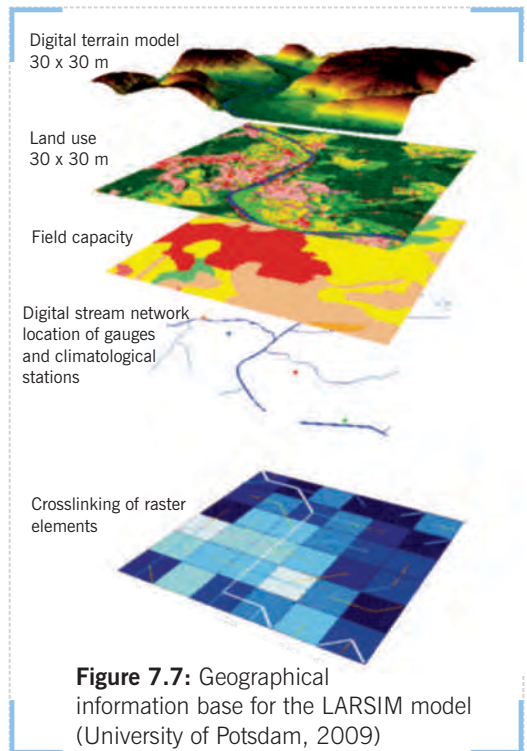
Among others the following hydrological processes are considered in LARSIM: interception, evapo-transpiration, snow accumulation, snow compaction and snow melt, soil water storage as well as storage and lateral transport in streams and lakes (Figure 7.6).

The geographical information base for the LARSIM model includes a digital terrain model, the land use pattern, the field capacity of the soils, the channel network with the location of gauges and meteorological stations (Figure 7.7).

The digital terrain network is analysed to get the flow direction, the height and the slope for each cell. From the land use map the percentage of each land use class is calculated for each cell. The digital channel network provides the length and slope of a channel reach in the cell. This information is largely extracted from a geographical information system.

For each cell up to 16 different land use classes with specific evapo-transpiration and runoff characteristics are distinguished. By use of Arc View-interfaces land use scenarios can be defined to evaluate their impact on water balance.

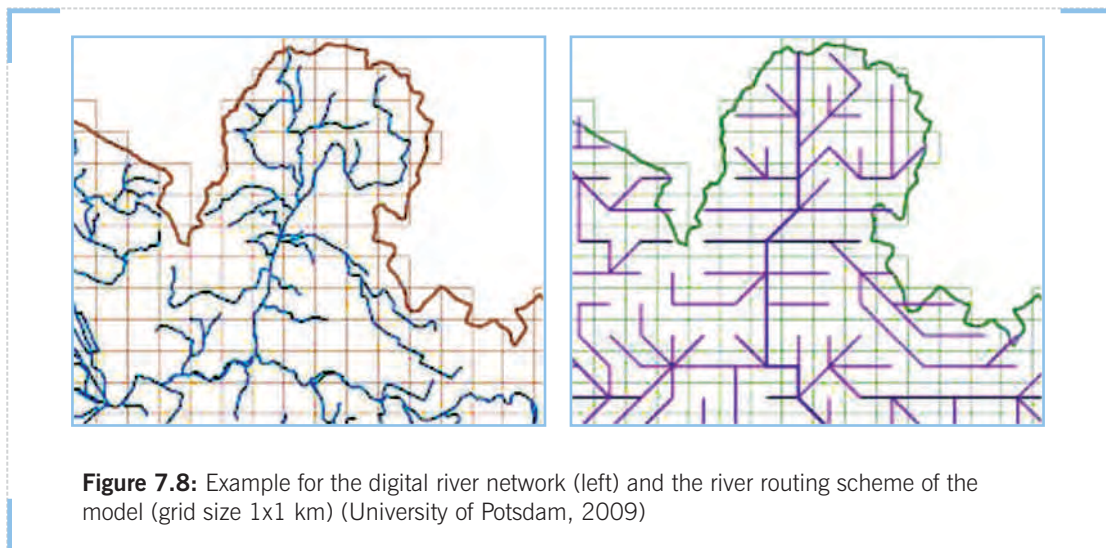
The reproduction of the real stream network is done by a calculative intersection of the digital stream network and the model raster (Figure 7.8). For each stream section geometric specifications about stream length and slope as well as width and height of the mean cross section are incorporated in the LARSIM system data set.



**Figure 7.7:** Geographical information base for the LARSIM model (University of Potsdam, 2009)

Surface or subsurface water flowing off of a grid cell may either flow into a channel or, if no channels exist, into the neighbouring down-slope grid cell. Therefore the grid cells have to be hydrologically connected in the model. In other words, water flowing from one grid cell flows to the down-slope grid cells and so on until the outlet of the watershed is reached (Figure 8.1).

Flood routing (chapter 2.5 “Channel flow and flood routing”, Figure 2.6) in the channel can be calculated by the Williams method of flood routing or by a simplified translation and linear storage concept, where the parameters are dependent from the roughness of the channel bed. Alternatively the inflows to the channels can be stored and flood routing can be calculated by separate hydrodynamic models using the results of LARSIM as lateral inflow to the channel.



Based on the meteorological data the water balance model computes spatially and temporally highly resolved states of the terrestrial water cycle's components (like evapo-transpiration, soil moisture and runoff). Meteorological model data are:

- series for precipitation,
- air temperature,
- relative air humidity,
- wind speed,

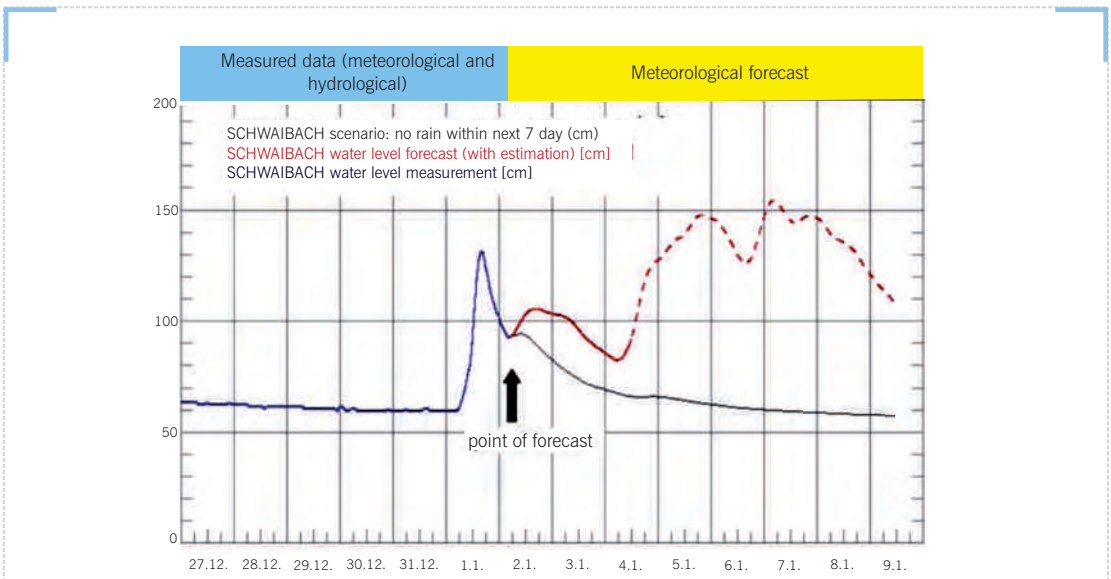
- global radiation, and
- air pressure

Concerning hydrological input, data that are considered are:

- measured gauge runoff,
- water transfer, and
- water management procedures like dams, regulation of lakes and retention basins.

If LARSIM is applied for operational flood forecast an automatic optimization routine analyses the difference between measured and calculated runoff and performs a correction of water yield or the actual water storage content according to the respective runoff situation.

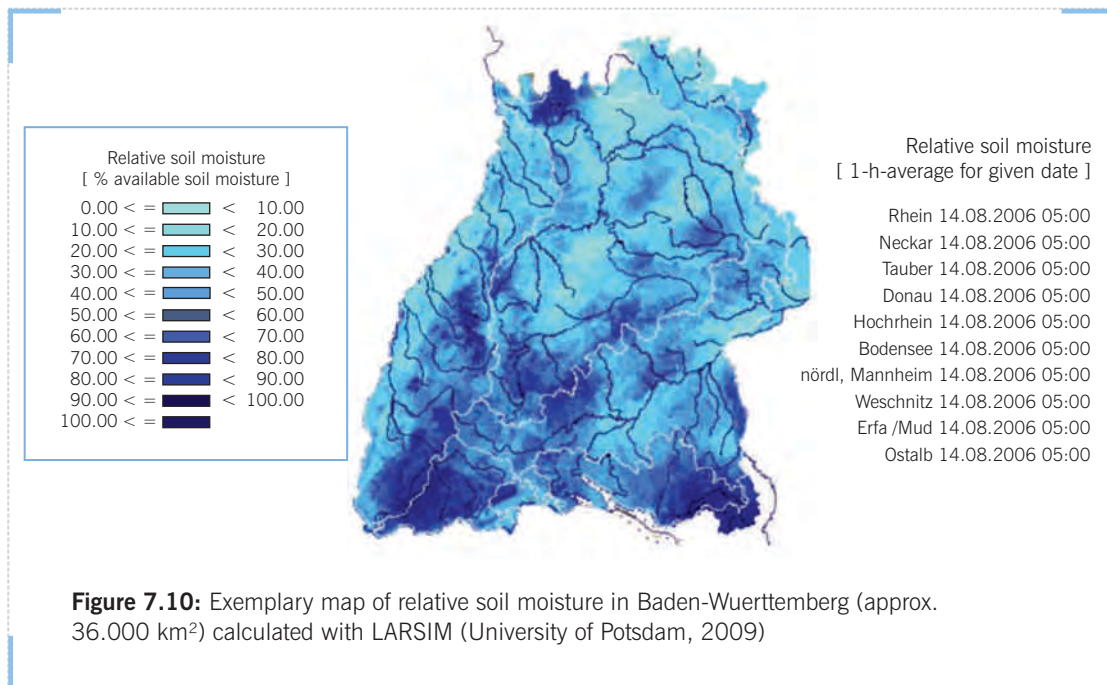
Based on the optimised model state the runoff forecasts are computed. Also the modelled snow cover can be automatically adapted to measured snow data.



**Figure 7.9:** Example of a flood early warning computed with LARSIM (gauge Schwaibach/Kinzig in the Black Forest, basin area 954 km<sup>2</sup>) (University of Potsdam, 2009)



The modelled results can also be exported and visualised as temporally aggregated spatial values, for example as maps of actual soil moisture (Figures 7.9 and 7.10).



**Figure 7.10:** Exemplary map of relative soil moisture in Baden-Wuerttemberg (approx. 36.000 km<sup>2</sup>) calculated with LARSIM (University of Potsdam, 2009)

The water balance model LARSIM can be operated in different temporal and spatial resolutions and is therefore suitable for many different tasks. Some examples are:

- Continuous forecast for low, mean and high water
- Forecast of water temperature
- Estimation of impact of environmental change like climate change or land use changes on water balance
- Prognosis and scenarios for river development planning
- Supra-regional determination of ground water recharge as basis for sustainable economy
- Supply of area-wide infiltration and runoff data for water quality models

Detailed information about the model basics can be found in Ludwig and Bremicker (2007).

## 7.4 Hydraulic models

Hydraulic models are used to calculate the movement of water by solving the physical hydrodynamic equations, thus providing projected water levels, flows and velocities. In flood forecast models they are used mainly to calculate flood routing. However, short computing times only allow 1-dimensional models, which only consider one longitudinal flow direction.

The advantage of hydraulic modelling compared to the simpler concepts of hydrologic flood routing methods like Williams or Muskin gum approaches, depends on the hydraulic conditions of the channel reach to be modelled, like geometric variance in direction of flow, areas of back flow and retention, flow braiding and confluence, constructions in and at the stream and stream conditions.

To make a rough guess (Werner et al., 2006):

- For steeper reaches, simpler routing methods provide sufficient accuracy. Because of their simplicity and computational efficiency, they have clear advantages over more complex full hydrodynamic modelling.
- For flatter reaches where backwater effects due to structures, confluences, or tidal influences affect the propagation of the flood wave, full hydrodynamic modelling is more appropriate.

## 7.5 The trend from 1 to 2-dimensional modelling

In practice the performance increase of computer hardware and of numerical methods and software ergonomics will facilitate a more widely spread application of two-dimensional models. Especially for the prediction of the process of flood plain inundation, a real-time prediction of spatial flood extent requires 2-dimensional modelling.

The perspective that forecasts will become more accurate is further supported by an increasingly available, growing database. For example modern photogrammetric methods like laser scanning and digital aerial picture processing allow the low budget acquisition of topographies of whole river systems and with a precision and resolution that is sufficient for a rough discretization used in two-dimensional modelling. After the first pilot projects, two-dimensional calculations have been preferred over one-dimensional calculations especially for the production of flood risk maps (TU Hamburg – Harburg, 2012).

To keep the advantage of simple routing methods like the Williams method there is the possibility to use the results of 2-dimensional hydraulic models to get volume – outflow relationships for channel reaches and apply

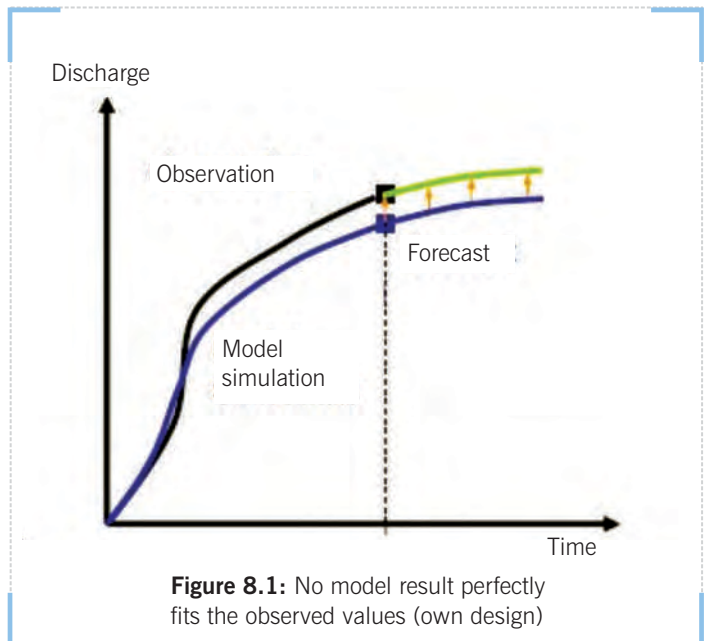
this relationship to the simpler routing method. For example, in situations where meanders are cut by the flood and the flow paths are shortened, it leads to significant better results in flood routing calculations. This method was applied successfully in the LARSIM-model.

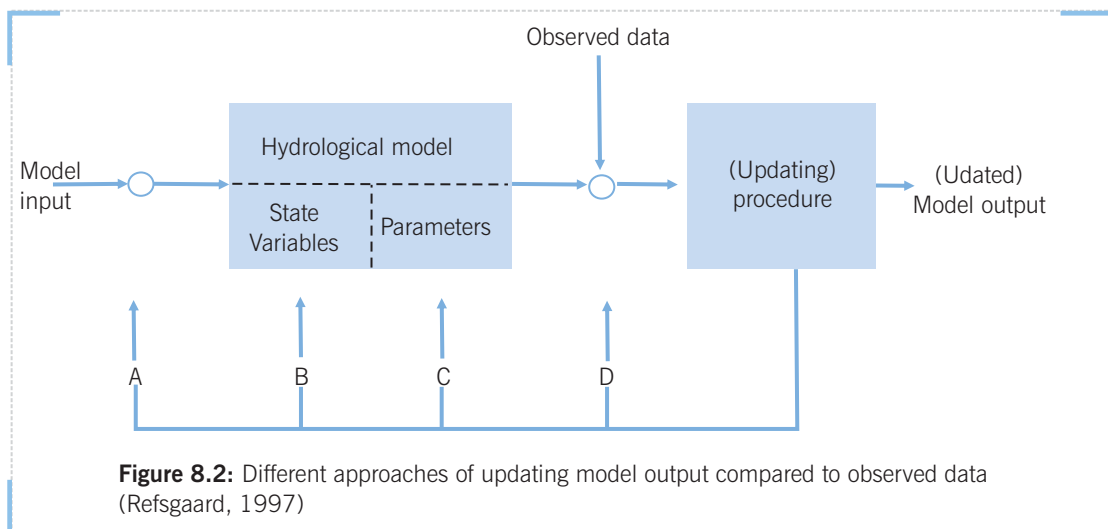
# 8

## LU-G: Updating and Assimilation

No model result perfectly fits the observed values. Both, the model and the available real-time data, must be seen as sources of information on the behaviour of the catchment, and both will contain some degree of uncertainty, resulting in differences between the observed data and the simulated data. Differences between forecast and observation at the forecast point are obviously errors in the forecast and/or in the observation. If these differences between model simulation and observation exceed errors in observations there is a need to correct the model simulation to reduce uncertainty in the forecast. This is best done with a feedback mechanism. Commonly referred to as data assimilation or updating, this feedback mechanism combines model output and observations and is a fundamental element of a forecasting system.

Model outputs are a function of the input, the model states and the model parameters. Thus there are four main approaches to update model output (Figure 8.1).





## 8.1 Updating of input variables

(approach A in Figure 8.2)

Particularly for hydrological rainfall-runoff models used in flood forecasting, the input variables are seen as the dominant source of error. These input variables, such as precipitation and temperature, or inflow discharge, are adjusted to minimize the differences between model output and observed variables. By the adjustment of the input variables the model states are also updated. In practice of flood forecast mainly precipitation input is corrected or adjusted. The other input variables have minor influence on the output in the flood case. Updating of input variables should only be done, if there are indications or evidence of the errors in the data and the amount of change of the data should be limited to a feasible value.

## 8.2 Updating of state variables

(approach B in Figure 8.2)

On the basis of the observed residuals, the state variables of the model are adjusted. These could be for example, soil moisture deficit values in a hydrological model, or water levels and discharges at the computational nodes of a hydrodynamic model. A number of approaches can be followed, ranging from simple to complex statistical filters. The simplest method is direct insertion, where a state variable is substituted by an observed variable. This is, however, not always conceptually correct because of the differences in interpretation

of what state variables and observed values represent, as well as issues of scale. More advanced methods include Kalman filtering approaches where state variables are adjusted in a physically consistent way using statistical assumptions of the spatial and temporal correlation of model errors.

### 8.3 Updating of model parameters

(approach C in Figure 8.2)

The error in the model is minimized through adjusting model parameters as a function of the errors found in model outputs. The model is thus allowed to adjust to changes in response to small changes in catchment behaviour not accurately identified when the model was initially set up. This approach is particularly applicable to data-driven modelling concepts, and has been applied to transfer functions, where parameters are not physically based. Physically based parameters in distributed models should be changed only in the limits of their strictness. They have to be recalibrated if the parameter values do not give proper results.

### 8.4 Updating of output variables or error prediction

(approach D in Figure 8.2)

Rather than correct the model or its inputs, in this approach, the statistical structure of the model error is considered, and based on the structure found, a forecast of the model error is made. The forecast variable obtained from the model is then adjusted with the forecast of the error to obtain an updated forecast. Commonly, statistical models such as an auto-regressive moving average (ARMA) model is used. The method is conceptually simple, and has the advantage that it is computationally efficient as no additional model evaluations are required.

In practice approach D is used in a very simple way to adjust the forecast to the last observed value by absolute and/or relative vertical displacement (Figure 8.1). Also most forecast models can apply a time lag to the simulation if a displacement in the rise of the hydrograph between simulation and observation appears.

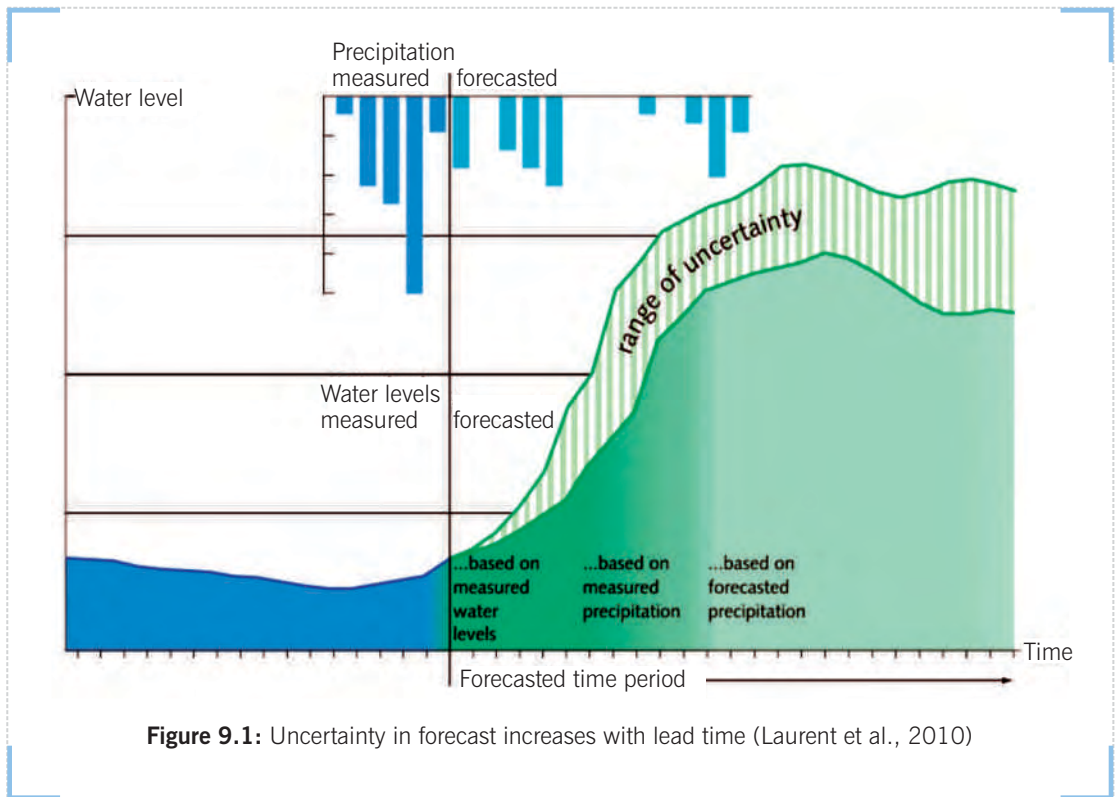


# 9

## LU-H: Quality Assessment and Uncertainty in Forecast

Experiences with published forecasts of flood events have shown the need for communicating the uncertainty associated with hydrological forecasts to the public and the responsible persons in civil protection. Expectations on the reliability of flood forecasts are high. Publishing only one forecast as a quasi-deterministic forecast with one value at a given time even raises these expectations by pretending to be exact. Therefore, one aim of computing uncertainty is to publish it along with the corresponding forecast. The resulting illustration should make the numeric forecast less absolute for the average user and communicate the probability of a certain water level to be reached.



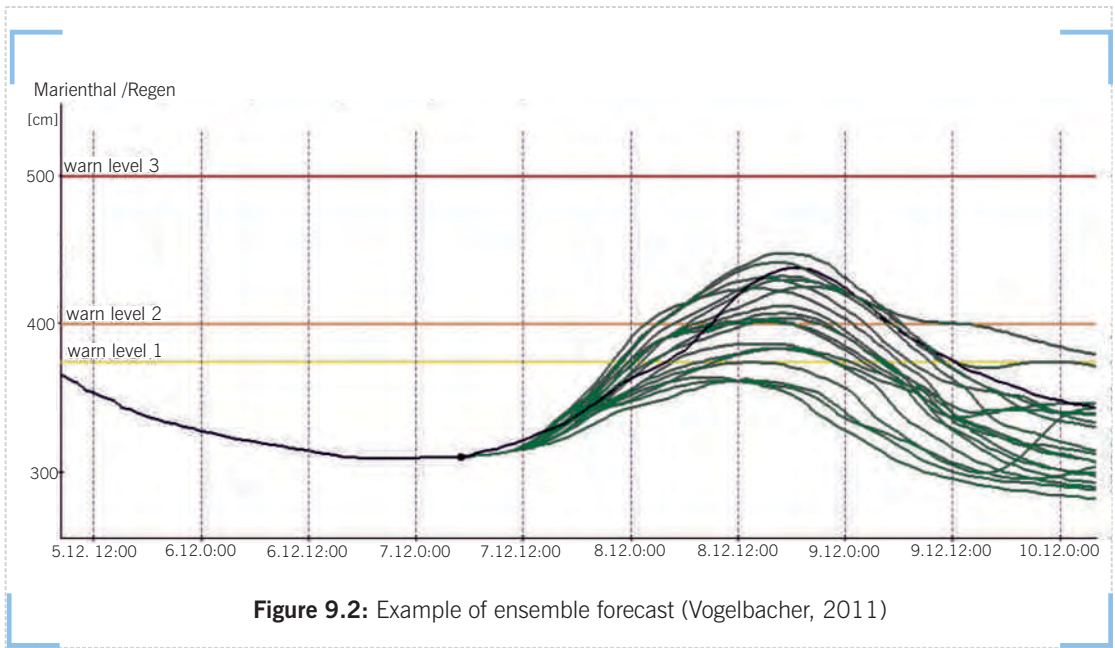


**Figure 9.1:** Uncertainty in forecast increases with lead time (Laurent et al., 2010)

The uncertainty in the flood forecast is the result of the

- Uncertainties in input data,
- Model simplifications,
- The estimation of the model parameters, and
- Operational practice of forecast generation.

Each of these components bears a particular uncertainty, which affects the uncertainty of the simulation output. In many cases, especially in headwaters, meteorological forecasts are the most dominant source of input data uncertainty. Often there are large differences in rainfall amounts between forecasts originating from different meteorological models and between the different model runs of the same model. Not only the



amount, but also the spatial and temporal distribution of precipitation can vary between different forecasts and the measured precipitation affecting the output of the hydrological model, especially in smaller catchments. Therefore, ensemble forecasts should be included in the calculation of total output uncertainty to account for the dynamic uncertainty of the meteorological forecast.

If the forecast horizon lies within the travel time of a flood wave observed upstream, the runoff forecast is expected to be more accurate as it only involves the single process of flood routing. Forecasts based on measured rainfalls are less accurate than those based on measured rainfall caused by the greater error in measurement and calculation of areal precipitation input (Figure 9.1).

The relative influence of the different sources of uncertainty depends on different factors like forecast horizon, meteorological conditions and up- or downstream location of the catchment. With increasing forecast horizon, the influence of the uncertainty of the meteorological forecast increases.

Considering all the sources of uncertainty, the optimal approach would be to do multiple forecast realisations by randomly varying all of the sources of uncertainty within their range (Monte Carlo simulation).

Because of operational constraints, a relatively straightforward approach for the calculation of forecast uncertainty has been applied in practice. Long time series of former, archived flood forecasts have been

compared to gauge observations calculating the relative error for each time step within the forecast horizon. From the error distribution obtained for each gauge, the relative error on the 10 and 90% exceedance probability level is used to illustrate the uncertainty on each new forecast. In addition to these “static” uncertainties the results of ensemble predictions are analysed and a combination of the “static” uncertainty with the “dynamic” uncertainty is calculated. Especially in headwaters, where the precipitation forecast is the dominating source of uncertainty, this is seen as an advisable procedure.

Communicating uncertainty to the users of the hydrological forecast is a very important task. As dealing with probabilistic numbers is not common to most users, descriptions and explanations should also be understandable to all. Adequate illustrations and descriptions should be evaluated in relation to the normal and advanced user. Additionally, experiences gained during future flood events might help in further adaptation of methods of communication.

For advanced users such as decision-makers in the water management authority, the published uncertainty should furthermore serve as a tool for better risk assessment. For example, the person in charge of operating a flood control basin can then base his decisions on probabilistic numbers in addition to the deterministic forecast instead of only on the latter. The responsibility for operators' increases as soon as he has to decide what probability threshold value should be taken into account. Therefore, it is very important to teach users how to interpret the published forecasts, especially the probabilistic part. Understanding the sources of uncertainty and their meaning also helps improving the correct usage of published prognostic data. This task is especially important since, compared to the normal weather forecasts; flood forecasts rarely gain the same every-day importance for the average user. Therefore, users are mostly lacking personal experience in evaluating the reliability of hydrological forecasts.

Overall, analysis and experiences with forecasts over the last few years show that the accuracy achieved so far could be improved in many cases. Hence, calculating and communicating uncertainty is one goal. A major goal, though, remains reducing the existing uncertainty in the data, the model, and its operation.

# 10

## LU-I: Organization and Operation of Forecast

The organization of the forecast system depends on the organizational environment framework of the operator. A flood forecast centre is linked to meteorological and hydrological services. The Political administration boundaries of counties, federal states or nations limit the area of responsibility for flood warning but the forecast system often needs basin wide monitoring. For larger river basins there is a need of cooperation between the neighbours. Nearly all possible constructs of collaboration in forecast can be found in Middle Europe. In Germany forecast centres are run inside the water management of the federal states, in some cases there are joint forecast centres of the federal state and the federation. The collaboration of the flood forecast centres consists in real time exchange of hydrologic and meteorological data and/or forecast products, which can be used as input data to the downstream forecast models. In some cases the forecast centres run models only of the sub basins inside their area of interest and use external forecasts for the sub basin outside or run their own models for the whole basin with input data from outside. This works well between equally equipped and developed neighbours. European organizations even run early warning system on a European scale.

An example of the organization of the flood warning service in Bavaria is given in chapter 3 section 3.1 of this study. The operating of the forecast is done by 5 forecast centres. Coordination, research and development are done by one flood information centre. All of the forecast centres use the same models and the same computer soft- and hardware to reduce the costs of development, maintenance, trouble shooting and operations.

The staff requirements depend from the size and the tasks of a forecast centre.

The size of a forecast centre can be measured by the extent of the basin areas, the number of measurement stations and the number of forecast gauges or locations (Table 10.1).The different tasks of a

flood warning system: real time data collection, forecasting, dissemination of the products and warning can be done in different organization units or even in different organizations. Most forecast centres don't operate the real time data collection of the measurement stations themselves but get the data from connected databases and/or via file transfer from meteorological and hydrological services.

**Table 10.1:** Size of forecast centres in Bavaria

Forecast Center	Total Basin Area [km²]	Basin area without external forecasts	Number of forecast gauges published	Total number of gauges
HVZ Donau	47,000	19,500	58	147
HVZ Inn	26,000	9,700	30	143
HVZ Main	27,000	22,000	33	146
HVZ Iller-Lech	18,800	14,800	15	114
HVZ Isar	8,400	8,400	24	96

## 10.1 Operating procedures

The essential operating procedures of a forecast centre are:

- input data management (get, check & correct, aggregate and /or interpolate data),
- model run & data assimilation,
- output data management, and
- configuration of automated runs of the system.

These procedures are done by the aid of computer software. The user interface should give an image of the system, which does not obscure the basic structure of the system. It should facilitate easy handling of input and output data and their appropriate displays and adapt the system for incorporation of additional data to improve the data base of the system (more rain stations, more gauge on tributaries). It should be possible to incorporate improved models and to exchange older models.

If possible, the programming of the user-interface can be done by own resources which gives the advantage of easy and fast adaption and facilitate maintenance. A widespread open source software is the DELFT-FEWS flood forecasting platform, which comes with forecasting tools for error correction, regression analysis, what-if scenarios and post event analysis. External data sources can be connected and different hydrologic and hydraulic models can be implemented. Results can be viewed and disseminated. The software is free but implementation requires the assistance of trained experts.

Forecasts should be done in regular time intervals. Hourly update of the forecast needs an automation of the operation procedures listed above. Table 10.2 shows an operation plan of a Bavarian forecast centre for the short and medium range forecast products.

**Table 10.2:** Forecast operation plan

ATTRIBUTES	EARLY WARNING (medium range)	FORECAST (short range)
Times of publication	Daily	During flood event
Update intervals	Daily	Hourly
Forecast horizon	Up to four days	4 to 24 hours
Accuracy of the forecast	Expected flood alert level	Flood level (20 - 50 cm)
Application	Preliminary actions	Protection measures

Hardware requirements depend on the number of working places for operators of the forecast. Our forecast centres work on client-server architecture with Linux Servers and Windows client workstations. A Browser based application and user interface has the advantage that no special software is needed on the client computers. We run the forecast models and the interface on Java-based client software with convenient workstations connected to a central database. Data exchange with external partners and import to the master database is done by server side scripts and software. To disseminate the products via internet a web server separated by a firewall is necessary. Often the servers are part of the IT-system in a computer centre of the organization.

All systems require redundancy and security measures to ensure uninterrupted operations. Thus, if external IT services and hosting of servers are used, the availability of the systems including the network connection has to be very high. If such services are not available the computer power has to be integrated in the forecast centre.

Full back up capability by another centre theoretically provides complete redundancy of the original centre's functions, but the cost is high. Because of the high cost and high probability of encountering problems due to

the infrequency of use, full backup should be used as a last resort, and each centre should strive to establish on-site redundancies in communications, hardware, and software (National Weather Service, 2010).

## 10.2 Staff

Different roles of the staff members are forecaster (hydrologist), technicians for the software and hardware computer environment, communication assistant who can interpret the forecast products to the public and answer phone enquiries. More roles may be added according to the tasks of the forecast centre. Each role has to be at least doubled staffed.

Extreme flood events are not very frequent. There can be years without any significant flood. Thus the staff can't get a lot of experience with extreme floods and training has to be based on operational scenarios and the experience of senior staff members.

Further staff related requirements are:

- Systematic plan for staff training and development
- Operations Manual to reduce the Centre's vulnerability to loss of staff or other unanticipated events
- Roles & Responsibilities: description of each subsystem operator's contribution at an operation level
- Staffing: listing of all staff required to operate the system in short and long-term

Manuals and documentation should include:

- Communication: description of the primary and redundant channels through which information will flow between and beyond each subsystem, i.e. monitoring networks, technology infrastructure, operating systems, computer applications, redundancy and backup capabilities.
- Data - inventory of the information requirements of each subsystem, including the need for historical data for model calibration as well as real time data for flood forecasting
- Skills development: description of the training, exercises and drill regime
- Models - description of the forecast models
- Products and Services - definition of the various outputs generated

**Important points to remember**  
about Maintenance Programs for Flash Flood EWS

- The need for a well-coordinated and supported maintenance program is critical to the success of a forecast centre's flash flood warning program.
- Whether a centre operates an in-house maintenance program, contracts out all maintenance, or has a program that is a mixture of the two approaches, it must track all maintenance activities in order to effectively manage the program.
- A centre should establish what constitutes reportable maintenance events. These are the events that should be tracked in order to maintain the centre's programs.
- There is international training available for many types of earth data gauge installation and maintenance.
- Training on other electronic devices like routers, satellite downlinks, and radio transmitters is more difficult to obtain, but should be budgeted for, as these types of systems are crucial to centre operations.

(National Weather Service, 2010)

**Questions**

What are the tasks of a forecast centre?

What does a forecast centre need?

What are the requirements in view of the staff and the computer hard- and software?

What are the roles and responsibilities of the staff members?





# Further Information

- A recommended guide is the “Flash Flood Early Warning System Reference Guide” by the U.S. National Weather Service.

It covers the whole warning system including not only flash flood but is applicable to river flood risks too. Especially the following aspects not mentioned here can be found in this guide:

- ▶ Communication requirements
  - ▶ Technological infrastructure (Operating systems and hardware, application programs, redundancy programs, maintenance program requirements)
  - ▶ Warning Dissemination and Notification
  - ▶ Community based disaster management
  - ▶ Development of a Concept of Operations
- Lectures and Tutorials about a lot of aspects of meteorology and hydrology especially flood risks and natural hazard can be found on the Website of MetEd. (<https://www.meted.ucar.edu>). Various figures in this paper are taken from there.
  - Especially for Flood Management there is an E-Learning course of the Technical University of Harburg (<http://daad.wb.tu-harburg.de/homepage/>). It contains also modules of flood forecast and models.



# Glossary

Baseflow	the long-term supply that keeps water flowing in streams.
Basin	the area that drains to a single outlet point.
Convective cooling	Cooling of air mass by lifting driven by convection (i.e. upward flow of moist air caused by heating of the ground).
Cyclonic cooling	Cooling of air mass by lifting driven by a cyclone (low pressure system).
Depression storage	Depression storage capacity is the ability of a particular area of land to retain water in its pits and depressions, thus preventing it from flowing.
Discretization	Discretization is the transformation of continuous differential equations into discrete difference equations, suitable for numerical computing.
Ensemble prediction	Multiple numerical predictions are conducted using slightly different initial conditions that are all plausible or using different forecast models to generate a representative sample of different forecasts. The multiple simulations are conducted to account for sources of uncertainty in forecast models.
Evapotranspiration	Evapotranspiration is the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves.
Flash Flood Guidance (FFG)	A numerical estimate of the average rainfall over a specified area and time duration required to initiate flooding on small streams. ( <a href="http://www.hrc-lab.org/giving/FFGS_index.php">http://www.hrc-lab.org/giving/FFGS_index.php</a> ).
Flash floods	Flood of short duration and high peak, which rises and falls rapidly.
Field capacity	Field capacity is the amount of soil moisture or water content held in soil after excess water has drained away which usually takes place within 2–3 days after a rain or irrigation.
Flood routing	Hydrologic process describing the movement of a flood wave down a river.
Forecast Horizon	Time span of the forecast.
Forecasting Point	Place (i.e. gauging station) to which the forecast belongs.

Head water	The water courses near the source or upstream.
Kalman filtering	The Kalman filter is an algorithm which uses a series of measurements observed over time, containing inaccuracies, and produces estimates of unknown variables that tend to be more precise than those that would be based on a single measurement alone.
Latent heat	The heat released or absorbed by a body during the process of a phase transition (i.e. melting heat) without change of temperature.
Lead time	Here: time span between the time of warning and the time of coming true of a flood event.
Monte Carlo Simulation	Monte Carlo methods are a class of computational algorithms that rely on repeated random sampling to compute their results. Monte Carlo methods are often used in Computer simulations of physical and mathematical systems.
Now casting	Forecast within the next 2 - 6 hours. In this time range it is possible to forecast smaller features such as individual showers.
Orographic cooling	Cooling of air mass by lifting caused by flow resistance at the ground, i.e. air flowing over a mountain area.
Phase change	Phase transition (i.e. from solid to liquid or to gaseous).
Rainfall loss	Here: part of rainfall volume, which is not contributing to the direct runoff volume.
Raster elements	
Response time	Time lag between the triggering event and the flood event, i.e. between the time of rainfall and the time of the flood peak at the catchment outlet.
Richards equation	The Richards equation represents the movement of water in unsaturated soils, and was formulated by Lorenzo A. Richards in 1931. It is a non-linear partial differential equation, which is often difficult to approximate since it does not have a closed-form analytical solution.
Sublimation	Sublimation is the process of transformation directly from the solid phase to the gaseous phase without passing through an intermediate liquid phase.
Vertical instability of atmosphere	Atmospheric instability is a measure of the atmosphere's tendency to encourage vertical motion of air. In unstable conditions, a lifted parcel of air will be warmer than the surrounding air at altitude. Because it is warmer, it is less dense and is prone to further ascent. Atmosphere stability depends partially on the moisture content. In a completely moist atmosphere, temperature decreases with height less than 6°C per kilometer ascent indicate stability, while greater changes indicate instability.

# Bibliography

Bayerisches Landesamt für Wasserwirtschaft (Hrsg.) (2004): Hochwasser – Naturereignis und Gefahr, Spektrum Wasser 1, München

Bayerisches Landesamt für Umwelt (2011): Flood Warning and Information - Flood Warning Service in Bavaria, Flyer

Elliot J., R. Catchlove, S. Sooriyu kumaran and R. Thompson (2005): Recent Advances in the Development of Flood Forecasting and Warning Services in Australia. International conference on innovation advances and implementation of flood forecasting technology

India Meteorology Department .www.imd.ernet .in.

Laurent, S. / Hangen-Brodersen, Ch. / Ehret, U. / Meyer, I. / Moritz, K. / Vogelbacher, A. / Holle, F.-K. (2010): Forecast Uncertainties in the Operational Flood Forecasting of the Bavarian Danube Catchment. In: Brilly, M. (Ed.), Hydrological Processes of the Danube River Basin. Springer Dordrecht Heidelberg London New York

Ludwig, K., M. Bremicker (Eds.) (2007): The Water Balance Model LARSIM. Freiburger Schriften zur Hydrologie, Band 22 Institut für Hydrologie der Universität Freiburg

Mauser, W. (2012): Internetvorlesung Hydrologische Modelle (<http://www.geographie.unimuenchen.de/internetvorlesung/index.php>) (Access Oct. 2012)

MetEd (2010): Education & Training Module - Runoff Processes. [https://www.meted.ucar.edu/training\\_module.php?id=805](https://www.meted.ucar.edu/training_module.php?id=805)

MetEd (2012): Education & Training Module - Hazardous Weather and Community [https://www.meted.ucar.edu/training\\_module.php?id=890](https://www.meted.ucar.edu/training_module.php?id=890)

MetEd (2011): Education & Training Module - Flash Flood Processes

[https://www.meted.ucar.edu/training\\_module.php?id=806](https://www.meted.ucar.edu/training_module.php?id=806)

Szöllösi-Nagy, A. (2009): Learn from your errors – if you can! Reflections on the value of hydrological forecast models

[http://www.unesco-ihe.org/content/download/4217/44300/file/IA\\_ASN.pdf](http://www.unesco-ihe.org/content/download/4217/44300/file/IA_ASN.pdf)

National Weather Service (2010): Flash Flood Early Warning System Reference Guide. University Corporation of Atmospheric Research 2010. Online version:

[http://www.meted.ucar.edu/communities/hazwarnsys/ffewsr/FF\\_EWS.pdf](http://www.meted.ucar.edu/communities/hazwarnsys/ffewsr/FF_EWS.pdf)

Refsgaard, J.C. (1997): Validation and Inter comparison of Different Updating Procedures for Real-Time Forecasting. *Nordic Hydrology*, 28, 1997, 65-84.

TU Hamburg – Harburg (2012): Flood Manager E-Learning. <http://daad.wb.tu-harburg.de/homepage/>

University of Potsdam (2009): OPAQUE – operational discharge and flooding prediction in head catchments, Internet Presentation <http://brandenburg.geoecology.uni-potsdam.de/projekte/opaque/>

Vogelbacher, A. (2011): Flood Warning in Bavaria. IN: Gupta, Anil K. and Nair, Sreeja S. (2011): Abstract Volume of International Conference Environmental Knowledge for Disaster Risk Management, 10-11 May 2011, New Delhi P 64, Conference Organised by NIDM & GIZ-ASEM

Werner, M.G.F., J. Schellekens, J.C.J. Kwadijk (2006): Flood Early Warning Systems for Hydrological (Sub) Catchments. In: *Encyclopedia of Hydrological Sciences*. Published Online: 15 APR 2006, 2005 John Wiley & Sons, Ltd.

WMO (2007): Prospectus for the Implementation of a Flash Flood Guidance System with Global Coverage. A joint proposal by CHy and CBS in collaboration with Hydrologic Research Centres, U.S. National Weather Service, U.S. Agency for International Development/ Office of Foreign Disaster Assistance. Presented at the XV World Meteorological Congress, Geneva, Switzerland, 7-25



## About NIDM

National Centre for Disaster Management (NCDM) set up under the Department of Agriculture and Cooperation, Ministry of Agriculture in March 1995. NCDM has been upgraded into full-fledged National Institute of Disaster Management in October 2003. Under the Disaster Management Act, 2005, the Institute has been entrusted with the nodal national responsibility for human resource development, capacity building, training, research, documentation and policy advocacy in the field of disaster management.

NIDM is steadily marching forward to fulfil its mission to make a disaster resilient India by developing and promoting a culture of prevention and preparedness at all levels. Both as a national Centre and then as the national Institute, NIDM has performed a crucial role in bringing disaster risk reduction to the forefront of the national agenda. It is our belief that disaster risk reduction is possible only through promotion of a “Culture of Prevention” involving all stakeholders.

We work through strategic partnerships with various ministries and departments of the central, state and local governments, academic, research and technical organizations in India and abroad and other bi-lateral and multi-lateral international agencies.





## About GIZ

The services delivered by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH draw on a

wealth of regional and technical expertise and tried and tested management know-how. As a federal enterprise, we support the German Government in achieving its objectives in the field of international cooperation for sustainable development. We are also engaged in international education work around the globe. GIZ currently operates in more than 130 countries worldwide.

### GIZ in India

Germany has been cooperating with India by providing expertise through GIZ for more than 50 years. To address India's priority of sustainable and inclusive growth, GIZ's joint efforts with the partners in India currently focus on the following areas:

- Energy - Renewable Energy and Energy Efficiency
- Sustainable Urban and Industrial Development
- Natural Resource Management
- Private Sector Development
- Social Protection
- Financial Systems Development
- HIV/AIDS – Blood Safety



PARTNER FOR SUSTAINABLE URBAN AND INDUSTRIAL DEVELOPMENT

## About the Indo-German Environment Partnership (IGEP) Programme

IGEP builds on the experience of the predecessor Advisory Services in Environment Management (ASEM) programme but at the same time strengthens

its thematic profile in the urban and industrial sector, up-scales successful pilots and supports the environmental reform agenda and priority needs of India.

The overall objective of IGEP is that the decision makers at national, state and local level use innovative solutions for the improvement of urban and industrial environmental management and for the development of an environment and climate policy that targets inclusive economic growth decoupled from resource consumption.

For information visit <http://www.igep.in> or write at [contact@igep.in](mailto:contact@igep.in)

## About ekDRM

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), GmbH, Germany (formerly GTZ and In WEnt) have entered in cooperation with National Institute of Disaster Management for a joint project “Environmental Knowledge for Disaster Risk Management” (ekDRM, 2010-12) focuses on capacity building and knowledge management for disaster risk management. The components of project activities include the following:

- Environmental statistics and decision support systems
- Environmental and natural resource legislation for disaster risk management
- Spatial/land-use planning for disaster risk management
- Natural Resource Management and Disaster Risk Management linkages (including integrating disaster risk management and climate-change adaptation, eco-system approach to DRR etc.)
- Post-disaster environmental services and role of EIA in context of disaster management.

Cooperation aims at promoting research, case studies, documentation, effective training methodologies, including blended learning approach, tools and methodologies and outreach activities like workshops, conferences developing and maintaining web-enabled human resource platform.



### About the Author

Dr. A. Vogelbacher graduated from University Freiburg 1981 and finished his doctoral thesis in 1984. After a half year stay at the Hebrew University, he was working for 6 years in a small computer firm developing and implementing software for water information systems. Since 1991 to 2005 he was a staff member of the state office for water management in Bavaria (Germany). Since 2005 he is head of the Flood Information Centre at the Bavarian Environment Agency. As head of the Flood Information Centre, he improved the system design of the Bavarian flood information service from a formerly phone based service to a modern computerized information network.







