Flood forecasting system for the Maritsa and Tundzha Rivers

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Abstract

Climatic and geographical characteristics of Maritsa and Tundzha River Basins lead to specific run-off conditions, which can result in extreme floods downstream, as occurred in August 2005 and March 2006. To improve the management of flood hazards, a flood forecasting system (FFS) was set up. This paper describes a forecasting system recently developed in cooperation with the National Institute for Hydrology and Meteorology (NIHM) and the East Aegean River Basin Directorate (EARBD) for the rivers Maritsa and Tundzha. The system exits of two model concepts: i) a numerical, calibrated model consisting of a hydrological part (MIKE11-NAM) and hydraulic part (MIKE11-HD) and ii) a flood forecasting system. For some basins both meteorological and discharge measurements are available. These basins are calibrated individually. The hydraulic models are calibrated based on the 2005 and 2006 floods. The hydrological and hydraulic models are combined and calibrated again. The flood forecasting system (using MIKE-Flood Watch) uses the combined calibrated hydrological and hydraulic models and produces forecasted water levels and alerts at predefined control points. The system uses the following input:

- *Calculated and measured water levels;*
- *Calculated and measured river discharges;*
- *Measured meteorological data;*
- *Forecasted meteorological data (based on Aladin radar grid).*

Depending on the available input the forecast lead-time is short but accurate, or long but less accurate. If one of the input data sources is not available the system automatically uses second or third order data, which makes it extremely robust. A data assimilation routine is used to update calculated water levels and discharges at the inflow points with the observed data. The difference between the calculated and measured series during the hindcast period is used to correct the water levels during forecast period. A Data Exchange Tool (DET) disseminates relevant information between the databases of NIHM and the EARBD, the flood forecasting system and a website that shows forecast bulletins.

Key words: forecast, floods, MIKE11 model, hydrological modelling, data assimilation

Introduction

Impact of flooding in Bulgaria

Several newspapers reported massive flooding in parts of southern Bulgaria in February of this year. Melting snow and torrential rainfall caused the river Tundzha to overflow it banks. The city Elhovo and nearby villages were cut off and parts of the town, market area, bus station and other infrastructure were flooded. Another 30 villages in south Bulgaria were left without electricity.

Figure 1 Flood along Tundzha River in February 2010 (the Sofia Echo).

Floods like these are not uncommon in Bulgaria. The most severe floods in the last years occurred in August 2005 and March 2006. In the summer of 2005 extreme floods occurred along the Bulgarian part of the Maritsa River. Hundreds of people had to be evacuated from their homes, and more than 12,000 people were left homeless. The extreme weather even claimed the lives of several people. Bulgaria's most important road and railway line were completely submerged and closed for days. The total material damage was estimated more than Euro 200 million.
Within a year, in the spring of 2006, another flood occurred along the Bulgarian part of the river Tundzha and the Turkish part of the river Maritsa. In November 2007 a large flood occurred as well near the Bulgarian – Turkish border in Maritsa.

National borders do not bound the problems of flooding. The floods had an impact on the riparian countries Greece and Turkey too. Huge problems occurred in 2006 in the Turkish town of Erdine, as it is situated at the confluence of the biggest river of Bulgaria, the Maritsa, and the main tributaries Tundzha and Arda. The border between Bulgaria and Turkey was closed that year due to flooding.

Why building a Flood Forecasting System?
After more than 20 years of relative minor floods during wet seasons, large floods started to occur more often since the end of the 90's. These years of absence of large floods resulted in negligence of political action and financial investment for structural and non-structural flood mitigation measures and maintenance of the riverbed and its embankments. The increased exposure to hazards caused by the present intensive development in meeting the needs of the rapidly increasing population is another considerable reason for the high level of damage in the river basins, as happened in e.g. August 2005 and early March 2006.

During the floods of 2005 and 2006 no modern, operational flood forecasting system (FFS) was available in Bulgaria. The lack of this system is the main problem blocking an effective mitigation of the consequences of flooding. In other words, with the availability of such a system the reduction of flood risk and damage is highly increased through the possibility of timely detection of floods and dissemination of information with water level observations and forecasts.

This paper describes the set up and possibilities of a FFS in a more general way. The description is made on the basis of a FFS for the Bulgarian rivers Maritsa and Tundzha developed in the end of 2008 in cooperation with HKV consultants, EGIS-BCEOM International, the National Institute for Hydrology and Meteorology (NIMH) and the East Aegean River Basin Directive (EARBD) (EGIS-BCEOM International et al., 2008). The geological and hydrological situation of the Maritsa and Tundzha catchments and the data infrastructure involved with setting up a FFS might be similar in reference with other catchments. The paper therefore describes first the study area and flood forecast systems in general whereupon the paper focuses on the strengths and possibilities of the methodology applied in Bulgaria.

Case study description

General

Before setting up a FFS a proper analysis should be made of the study area, in order to point out vulnerable areas. The description made here of the Maritsa and Tundzha catchments emphasises why the area is flood prone.

The Basin of Maritsa River is the biggest on the Balkan peninsula, having an area of more than 21000 km^2 within the Bulgarian territory. The total length of the Maritsa River is approximately 480 km with an average slope of 7.7 ‰. Its springs are situated just below the Musala Peak (2925 m) in the Rila Mountain. The Maritsa River collects its waters mainly from the south (Rodopian Mountain) and from the north (Stara Planina, Sredna Gora Mountains). Eventually, the Maritsa River flows into the Aegean Sea.
The maximum discharge of the Maritsa in 2005, 2006 and 2007 was approximately between 1000 m^3/s and 1200 m^3/s. The biggest tributaries are the rivers Tundzha and Arda, joining Maritsa at Erdine just across the border with Turkey. The area of the Tundzha river basin is around 8000 km^2 within the Bulgarian territory. The Tundzha river length is approximately 350 km with an average slope of 5.8 ‰. Its springs are situated just below the Botev Peak (in Stara Planina Mountain). The maximum discharge of the Tundzha during these years is between 50 m^3/s and 200 m^3/s. The total area of both basins (around 29000 km^2) is about ¼ of the Bulgarian territory.

Topology

Both river basins are densely populated, with intense agriculture and quite developed industry. The biggest cities in the basins are: Plovdiv (more than 350 000 inhabitants), Pazardjik, Stara Zagora, Haskovo, Sliven and Yambol. 25-30 % of the whole area of the basins is cultivated land and situated in the valley and plains. The hilly areas are used as pastures, vineyards or to cultivate potatoes. Forests cover about 40 % of the watershed.

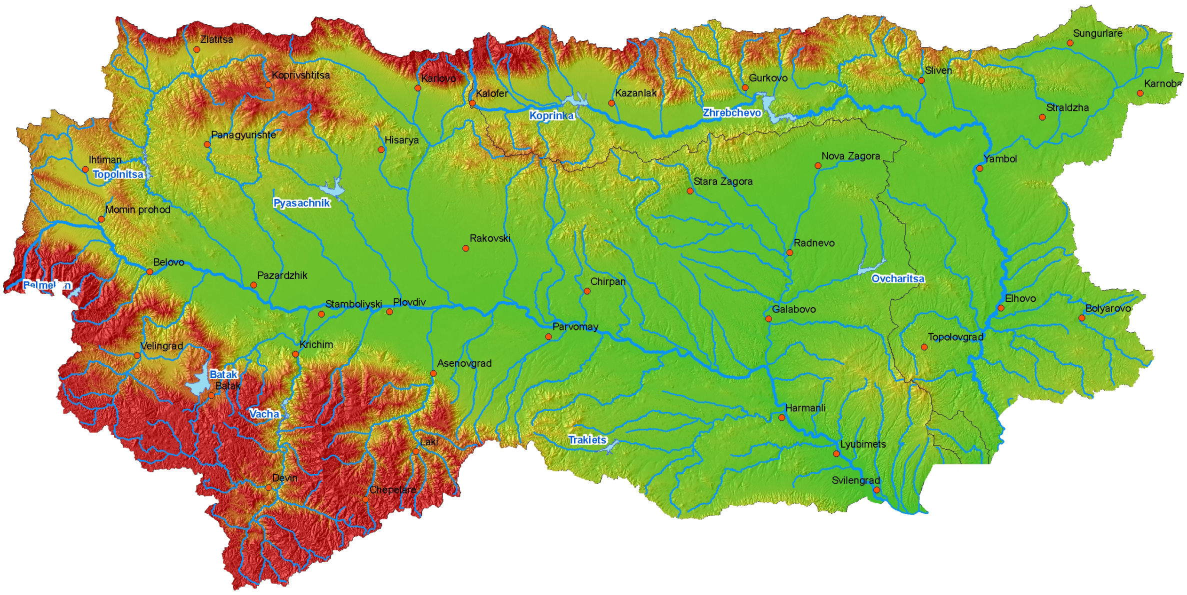

Figure 2 Catchments of Maritsa and Tundzha River.

The Maritsa River flows between Pazardjik to Parvomay in a large flat plain. The dikes along the river are not very well maintained out of the main cities. Downstream Parvomay, the relief becomes hillier and the floodplains are reduced in size until the Greek-Turkish borders, where the floodplains get again wide and flat. From Yambol to Elhovo the floodplain along the river Tundzha is very large and flat and the river freely meanders within large forested areas until the town of Elhovo. Downstream Elhovo the river slope increases again through an unpopulated hilly relief which constraints its discharges in narrow cross sections down to the Turkish border. In Turkey the river flows into a large and flat floodplain again, where it meanders (though it has been canalised) until Erdine where it joins Maritsa.

Flood genesis

The climatic and geographical characteristics of Maritsa and Tundzha river basins lead to specific run-off conditions: flash floods, high inter-annual variability, heavy soil erosion reducing the reservoirs' capacities through sedimentation. The destructive forces of climatic hazards, manifesting themselves in the form of rainstorms, severe thunderstorms, intensive snowmelt, floods and droughts, appear to increase during recent years. Basically the Maritsa and Tundzha river basins face four types of floods:

- Winter floods (December to mid February): generally caused by a single or more likely series of Mediterranean cyclones propagating eastward from Mediterranean Sea across the Balkan peninsula. Such situations, where the primary driving force is the dynamic of the atmosphere, produce intensive repetitive rain throughout the basin and result in large and long floods in the lower Maritsa;
- End of winter early spring floods: Their genesis is the same as above, but with sudden air warming generally associated with large polar front waves generating meridional circulation; They are often worsened by the effect of snow melting due to a rapid advective warming over a well prepared land covered with a relatively thick fresh snow at low altitude;
- Spring and early summer floods (later in case of rainy summers): Convective precipitation along the cold fronts of slowly moving cyclones (eastward) re-alimented by soil moisture. These types of precipitations will touch the upper basins of both Tundzha and Maritsa and may produce large flash floods in these areas. Here the convection is the primary driving force for the formation of precipitations;
- Fall season floods: Generated by slowly moving cyclones, which centres follow the Balkan coasts then move eventually to the Black Sea. Convective precipitations are alimented by the warm seawater from the Mediterranean Sea to the Black Sea. The precipitations will touch mostly the lower parts of Maritsa and Tundzha.

Reservoirs
Within the Maritsa and Tundzha catchments, in the upstream sub basins, a significant number of reservoirs and cascades are constructed for irrigation purpose and for hydro-electricity production. Obviously, these dams affect the flood regime and statistics. The frequency and magnitude of flooding appear to be higher before 1960, before most reservoirs were constructed. On the other hand, the extreme floods might remain the same, because, once the reservoir is filled, it will overtop. The problem is that operational rules for flood retention purpose conflict with reservoir procedure for irrigation and hydropower purpose in terms of storage and release. Within this project no information was available about the operational rules of reservoirs.

Principles of FFS

General explanation of functionality FFS

Flood waves propagate in rivers in a well-known way, which is relatively easily modelled and routed with the appropriate mathematical models, which have to be calibrated and validated. Floods are caused mainly by rainfall or snowmelt. Depending on the size and characteristics of sub basin and the length of a river the response time of sub basins on rainfall differs in reference with the time scale of flood propagation from upstream to downstream of the watershed. However, the time scale of forecasting a flood situation (lead-time) varies along the distance where the rainfall occurred. Depending on the available input the forecast lead-time is short but accurate, or long but less accurate, as stated in figure 3.

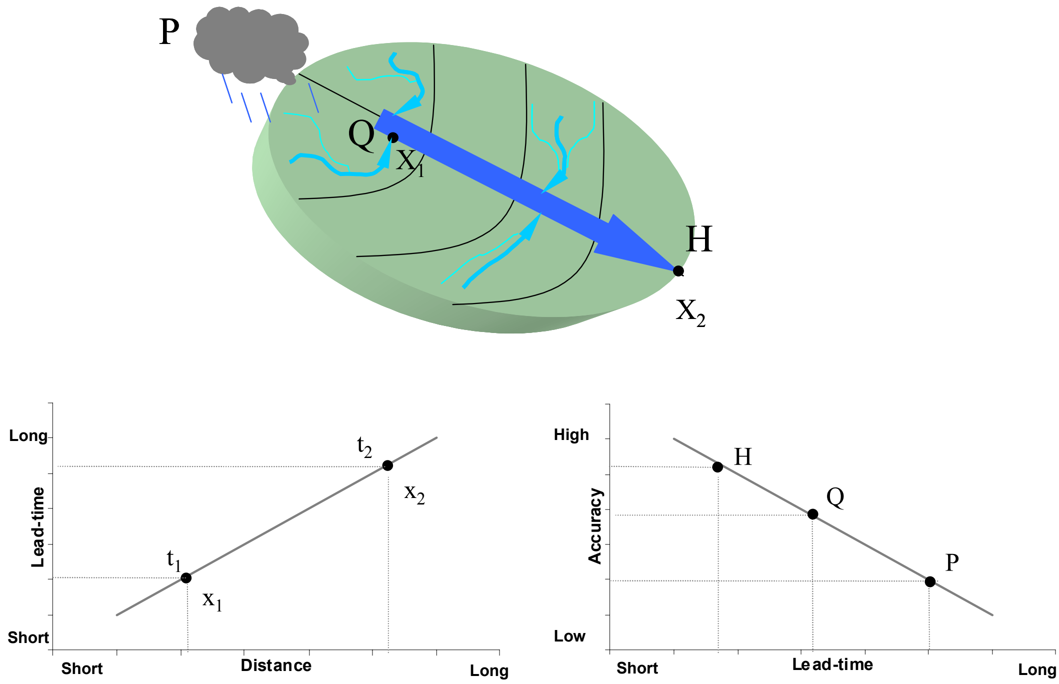

Figure 3 Theoretical relationships between lead-time, distance to rainfall (left) and accuracy of forecasted water level on point X_2 (right) (P = rainfall, Q = discharge and H = water level).

The forecasted water levels are disseminated to relevant authorities and stakeholders. When floods are forecasted a crisis team should be formed that will inform local authorities and stakeholders in order to make proper decisions. After the flood (threat) the system and procedures should be evaluated and if needed updated. A general overview of a FFS is given in figure 4.

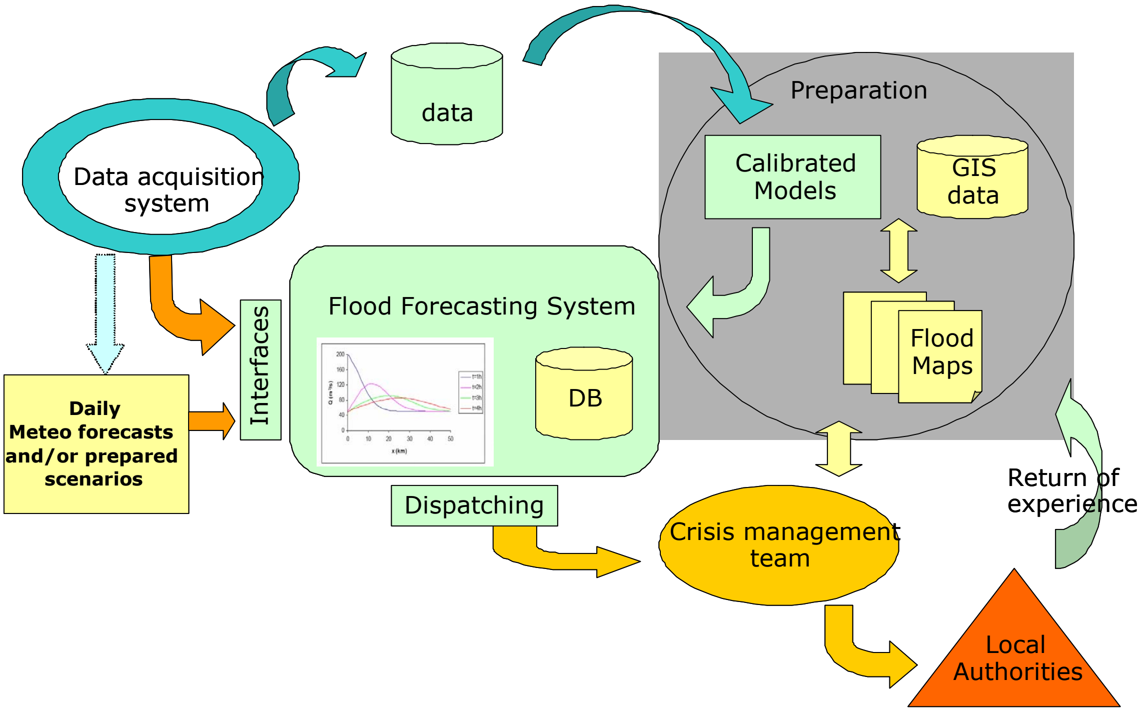

Figure 4 Overview of flood forecasting system organisation.

Examples of FFS
All over the world flood forecast systems are implemented, each with it's own spatial coverage, demand of input, and accuracy of the results. However, flood-forecasting systems share one general purpose:

From a general situation that is observed at several points (water levels, discharges, rainfalls, snow cover, soil moisture, etc.) the purpose is to know how the river situation will be in one or several days.

Two examples of operational flood forecasting systems are given.

In the Netherlands 240.000 people are evacuated after threatening high water levels at the river Rhine in 1995. This was the motive of the International Commission of the Rhine to improve the forecasts. The new system based on FEWS consists of a one-dimensional hydro dynamical model of the Rhine from Karlsruhe to Lobith and rainfall runoff models for all the tributaries from Basel to the German-Dutch border. The regional authorities in The Netherlands are now able to make flood forecast with a lead-time of four days at the gauging station Lobith just after the German-Dutch border (Flood Control 2015, 2008).

At the Regional Flood Management and Mitigation Centre in Phnom Penh Cambodia an advanced hydrological flood-forecasting model for the Lower Mekong River Basin was developed using the URBS rainfall run-off routing model in a FEWS environment. Also a framework for testing the accuracy of new models for 2006 and 2007 using Satellite Rainfall Estimates and NOAA forecasts was prepared, by developing robust GIS algorithms converting spatial data into input for the model. During the flood season (June-October), five-day flood forecasting and flow forecasts are conducted along the Mekong mainstream and updated daily using the developed flood forecasting system (Pengel et. al, 2008).

FFS applied in Bulgaria

Model set-up
Until 2008 no operational FFS was available in Bulgaria. The case study described in this paper was focused on setting up an operational system using existing data infrastructure and to combine it with the existing organization. The system uses the following measured data, each with its own temporal resolution, gathered from the automatic telemetry system at NIMH:

- Water levels;
- River discharges;
- Meteorological data;
- Forecasted meteorological data based on Aladin radar grid, see textbox 1.

In order to assure a closing water balance and to calculate realistic water levels a FFS should cover the complete catchments. This means that every drop in the catchments is taken into account. Moreover, as the main goal of the system is to predict high water levels, the numerical models should be calibrated on high water periods to assure the models reacts on heavy rainfall properly. A numerical calibrated model with a hydrological part and a hydrological part, the so-called water management model, is the main part of the flood forecast system. In case of the Maritsa and Tundzha FFS, the water management model consists of rainfall run-off models (MIKE11-NAM) covering the sub basins and 1-dimensional hydraulic models (MIKE11-HD) (DHI, 2008a), covering the main rivers, see figure 5.

An overview of models applied is shown in figure 6.

Aladin (Aire Limitée Adaptation dynamique Développement InterNational) is a numerical short range meteorological forecast model developed within an international team. In case of the Maritsa and Tundzha FFS, Aladin input data consists of initial boundary conditions from a global meteorological model Arpege and local relief data. The provided input for the hydrological models are predicted precipitation, temperature and eventually computed potential evapo-transpiration, based on spatial grid with a resolution of 9 by 9 km. Potential evapo-transpiration is computed using the wind speed, temperature, solar radiation and air moisture data provided from Aladin model. In this project, the maximum forecast lead-time of meteorological data is 72 hours (*www.cnrm.meteo.fr/aladin*).

Textbox 1 Aladin

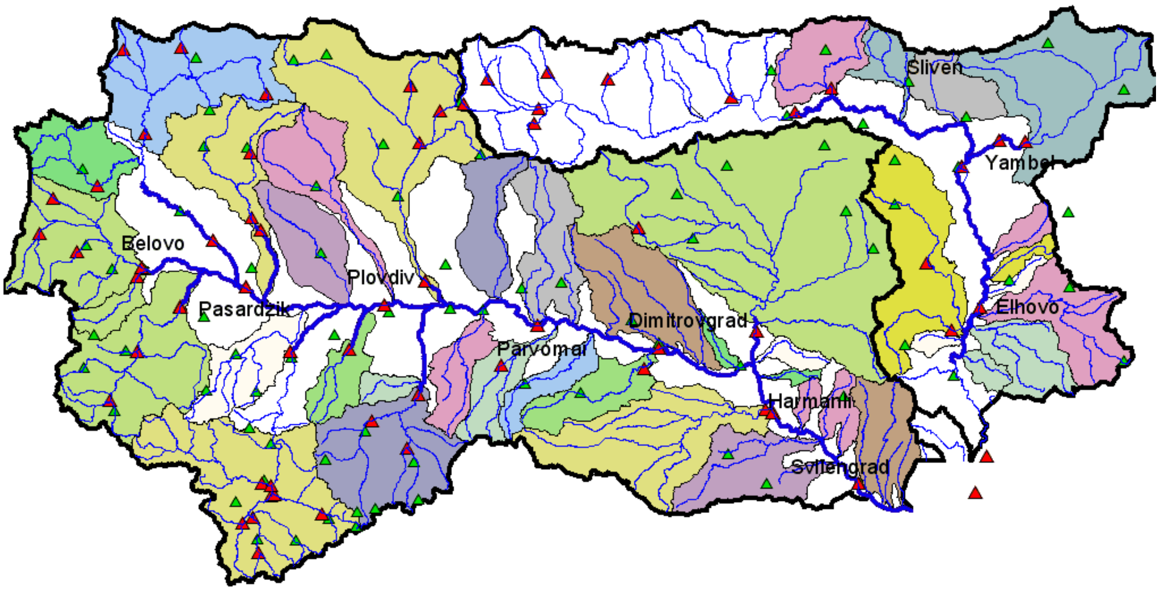

Figure 5 Catchments divided in sub basins (NAM model) and main river (HD model).

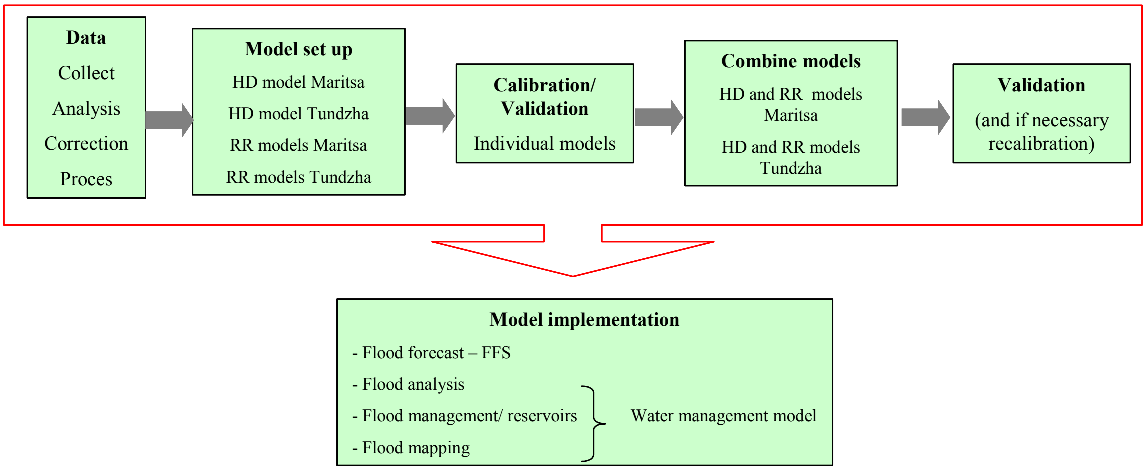

Figure 6 Model structure involved in FFS. (RR = rainfall runoff, HD = hydraulic)

Every forecast simulation is stored as a whole. This means that not only the results are available, but the model itself as well. When a flood occurs, the models can be used afterwards to evaluate the system performance, but also to assess flood mitigation measures related to the flood occurred.

Hydrological model (RR)
All sub basins are simulated with NAM models. The NAM models feed the hydraulic model. NAM is a lumped, conceptual rainfall-runoff model. Being a lumped model, NAM treats each catchment with one single unit. The parameters and variables represent, therefore, average values for the entire catchment. NAM represents various components of the rainfall runoff process by continuously accounting for the water content in four reservoirs: Surface water, root zone, ground water zone and snowmelt. Being a conceptual model, NAM is based on physical structures and equations used together with semi-empirical ones. As a result, some of the model parameters can be evaluated from physical catchment data.

For the NAM models the following set of data was used:

- Daily average temperatures for the catchments;
- Daily totals of precipitations;
- Monthly average totals of potential evapo-transpiration for each basin;
- Daily discharges – for the gauged catchments.

As the model is simulating everything in one point it is obligatory to use a single time-serie of a given type or so called weighted averages time-series in cases when there are more than 1 station of a type in the catchment. During the project it is decided to make a single time-serie for the temperature and to use the weighting function for the precipitation. The main reasons for that decision was that the temperature shows more stable variation with the height than the precipitation as shown in figure 7.

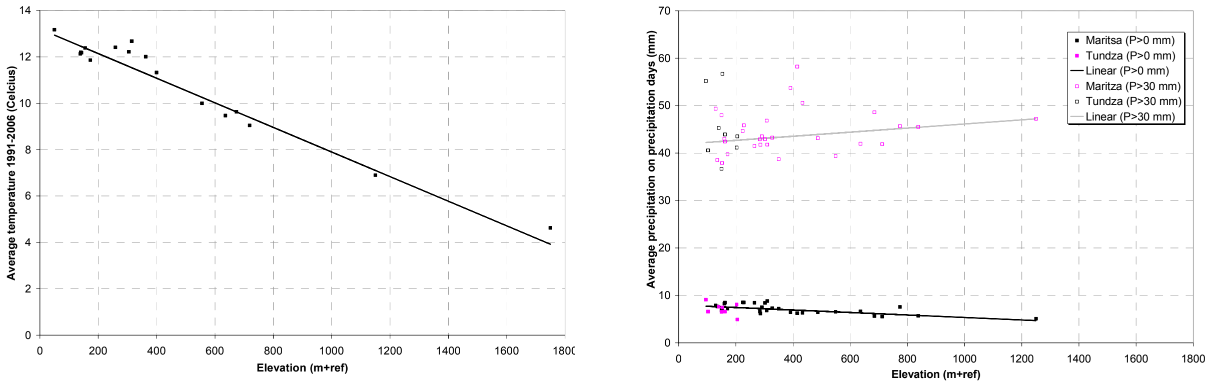

Figure 7 Temperature lapse rate (left) and precipitation lapse rate (right).

Since the functioning of the weather systems within the local geography is rather complex, the stations are weighed based on distance (Thiessen method). Influences of the local aspects in the weather systems and geography are neglected. Nevertheless, for some of the catchments better results for the peak discharges were achieved with some changes in the weights of the used precipitation stations (Koshinchanov et al., 2009).

Hydraulic model (HD)
The rivers Maritsa and Tundzha and the main tributaries are simulated with the 1 dimensional hydraulic model MIKE11-HD. The hydraulic models, with time series of discharges as input of the inflow, are calibrated on high water levels of 2006 by adapting the hydraulic roughness and validated on high water levels of 2005. An example of a calibration result is shown in figure 8.

Models combined
After calibrating the hydrological and hydraulic models individually, all NAM models of the sub basins are combined with the HD model. The discharge measurements are replaced with calculated outflow of the NAM models and the combined models are validated and if necessary recalibrated again.

Sub basins that have meteorological stations within its catchments and discharge measures at the downstream boundary of its catchments are selected for calibration. The calibration is focused on high water periods. Being a conceptual model, NAM is based on physical structures and equations used together with semi-empirical ones. As a result, some of the model parameters can be evaluated from physical catchment data, but the final parameter estimation must be performed by calibration against time series of the observed discharge

After calibrating the gauged sub basins, the parameters of these sub basins are transformed to non-calibrated NAM models (where calibration series are not available) with similar characteristics. Characteristics are based on soil types, area size and flat or hilly area. This method indicates that with relative few data a complete catchment can be covered by rainfall run off models.

Textbox 2 Calibration NAM models

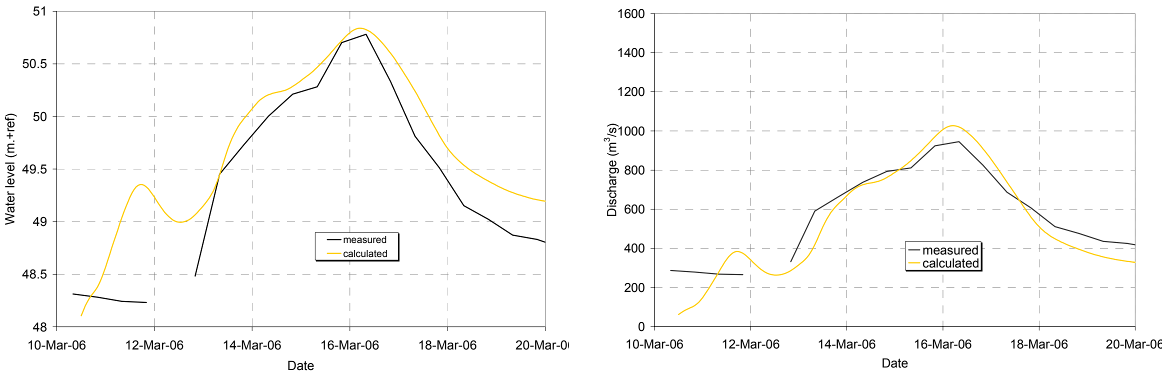

Figure 8 Calibration result for Svilengrad along Maritsa River during 2006 flood.

Flood forecasting methodology

The Maritsa and Tundzha Flood Forecasting System consists of the calibrated hydrological models and hydraulic models. The system is based upon MIKE Flood Watch software (DHI, 2008b) as front end, which we configured and interfaced for our purpose. Every day at least one simulation is made with 5 days forecast on predefined control points. Per control point 3 alert levels are defined: warning, pre-alert and alert. The frequency of simulation is depending on the frequency of the available incoming input. For example, simulation of the forecast system 4 times a day based on measurements with a frequency of 1 day does not provide extra information. Normally, the frequency of the measurements will be increased during high water periods. In that case, the frequency can easily be increased manually. A longer forecast period is of course possible, however the accuracy will be reduced.

The forecasted water levels can be improved by making use of a comparison between the measured water levels and computed water levels of the initial number of days in the calculation period (hindcast period). In this case a hindcast period is taken of 5 days. Some "optimal analysis" between forecasted values and observed values must be done in order to produce new initial conditions to the model for the next run. Within the Mike Flood Watch software a weighting function routine in the Data Assimilation module is used. The average error between calculated and measured during assimilation is used to correct the calculated series during the forecast period. Data assimilation is done for water level data and discharge data at existing and planned stations.

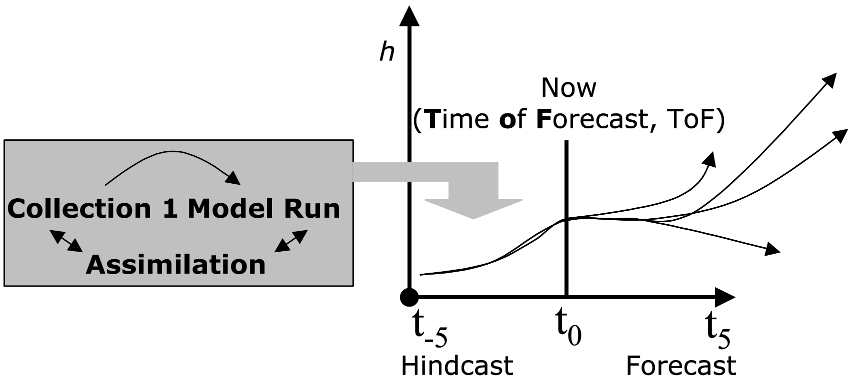

Figure 9 Data assimilation on hindcast period

To assure a continuous flow of input data, the system uses a data series hierarchy in which for each input data different orders are defined as stated in table 1. Eventually, Mike Flood Watch combines different, available sets of input and triggers the MIKE11 HD and NAM models in order to calculate forecasted water levels. More than 300 unique time series were used. This means if for example, for a rainfall station no rainfall time series is available, the system automatically takes the next order, which is the forecasted rainfall. This set up makes the system very robust.

Data	Order		
	1	2	3
Water level	Measured	Calculated[1)]	
Discharge	Measured	Calculated with NAM models based on measured meteorological data[1)]	Calculated with NAM models based on forecasted meteorological data[1)]
Meteorological			
Rainfall	Measured	Forecasted[2)]	Constant
Temperature	Measured	Forecasted[2)]	Constant
Wind	Measured	Forecasted[2)]	Constant

Table 1 Overview of input data ([1)] corrected with assimilation, [2)] using Aladin)

The table above is illustrated with an example in figure 10.

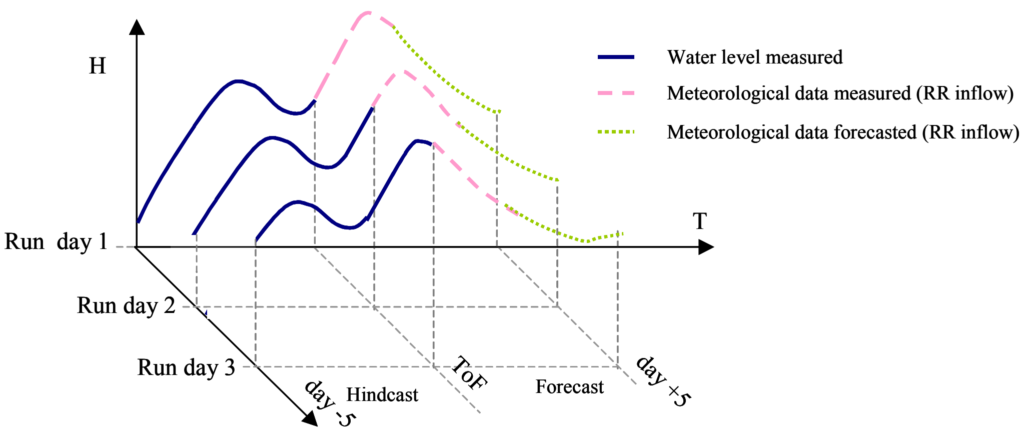

Figure 10 Illustration of forecasted water level based on different data

Data Exchange Tool

In general a flood forecasting system should consist of different components:

- Input component

Meteorological forecasts, measured meteorological and hydrological data and external measurements like data from neighbouring countries, are collected within the input component. All data is stored in the input database.

- Forecast component

Hydrological and hydraulic calculations are made within the forecast component. Forecasts can be made by making calculations with the hydrological and hydraulic models using the forecasted data as input. Precipitation in the upstream parts of the forecasting model travels downstream during a certain period of time. Taking this into account we can assume that forecasts in the downstream parts of the model are not only based on forecasted data, but also on measured data upstream. The forecast component normally uses the calculated forecasts to fill predefined bulletins.

- Output component

The output component stores and disseminates the forecasted and historical data.

- Backup component

Normally a backup component should be available as well. It is essential that when the model crashes there is a backup system running and a procedure that ensures restarting of the forecasting system.

Figure 11 illustrates the standard forecasting components.

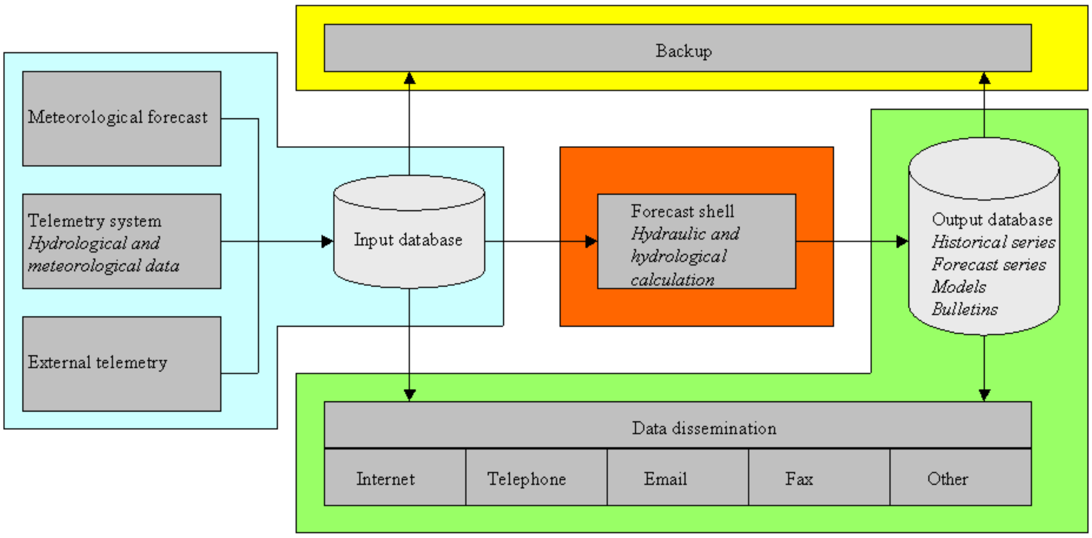

Figure 11 Overview of standard forecasting components

Within the described study we wanted to use existing systems, infrastructure and data flows as much as possible. In order to connect all existing and new developed systems and databases the Data Exchange Tool (DET) was developed. The DET manages the input, forecast, output and backup components. The components exists of:

- Input component

Meteorological forecast is collected from the Aladin radar grid. Meteorological and hydrological measurements are gathered from the automatic telemetry system at NIMH. The objective is to include Turkish data at the downstream model boundary as well, especially when flood thread is eminent.

- Forecast component

The Mike models make the forecast calculations. They are automatically activated daily, or more frequent in emergency situations, by the Mike Flood Watch module.

- Output component

Forecasted time series, bulletins and warnings are stored in the DET database. All available data is disseminated using the internet. Stakeholders can login to the website and depending on their profile the type of forecast data can be accessed. For instance downloadable time series are available for professionals and not for the public. The latter can only access general bulletins and warnings. A screen dump of the flood forecasting dissemination website is shown in figure 12.

- Backup component

The Flood Watch database, containing the input data and models, is replicated every day and send to the EARBD. The results are stored and archived in the DET database as well.

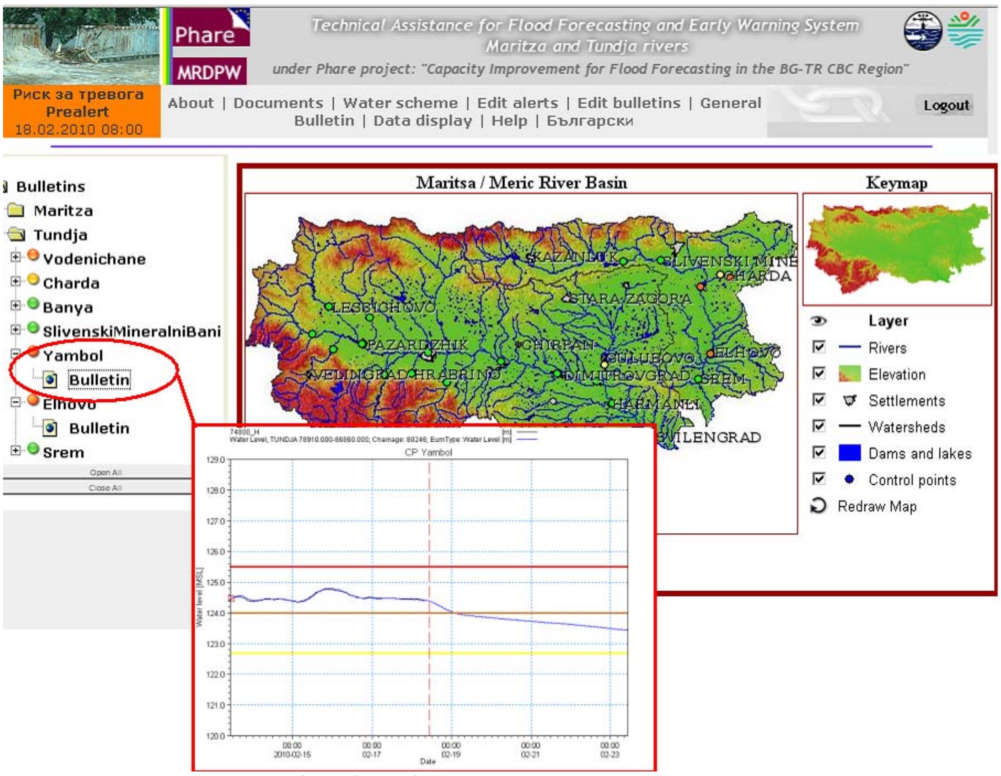

Figure 12 A screen dump of the flood forecasting dissemination website

Figure 13 shows the different flood forecasting system components and their relation with the DET.

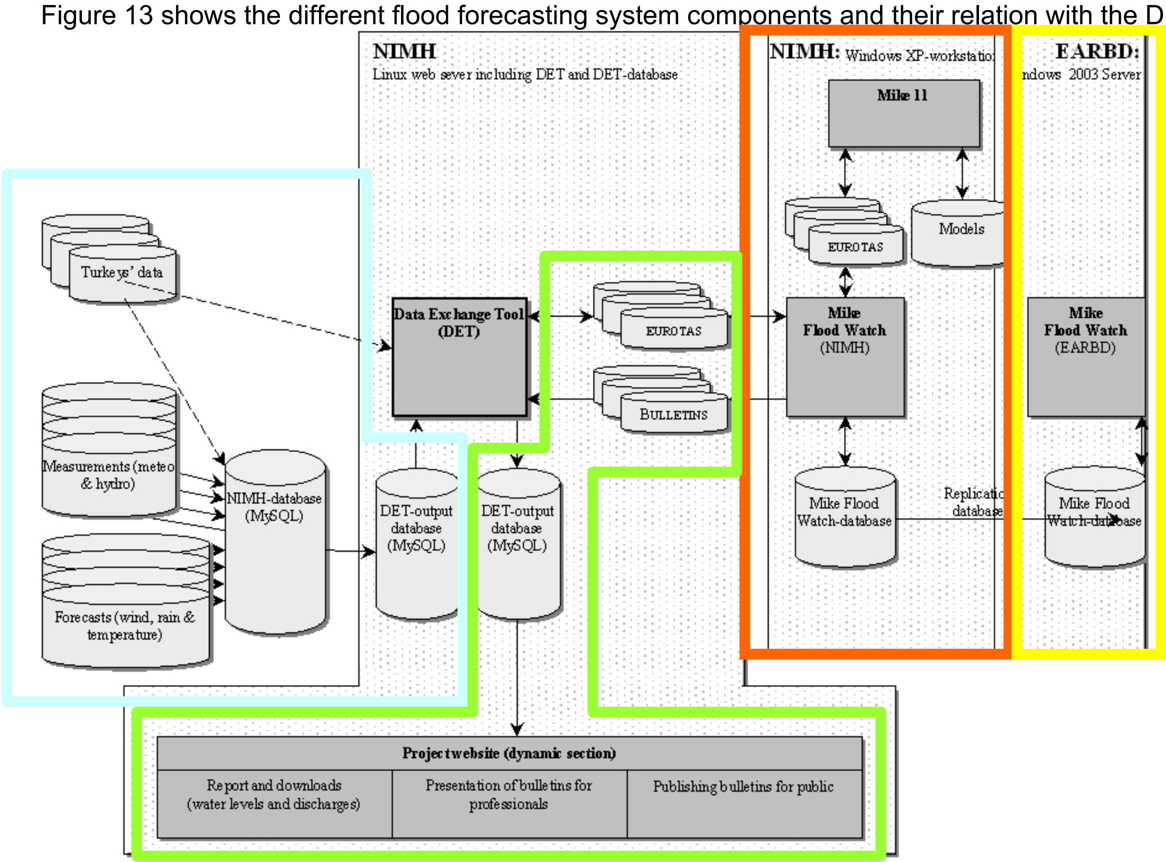

Figure 13 Function of DET within Maritsa and Tundzha FFS

Conclusions

On the basis of the description of the Flood Forecasting System for the Maritsa and Tundzha rivers the following conclusions can be made:

- In a flood prone area an accurate Flood Forecasting System is very important in terms of detecting timely high water levels and dissemination of information in order to reduce flood risk and damage. The time scale of forecasting a flood situation (lead-time) varies along the distance where the rainfall occurred. In case of the Maritsa and Tundzha system, the maximum lead-time of forecasting water level is approximately five days.
- To forecast water levels downstream in a proper way, hydrological and meteorological information of the complete upstream area should be collected. However, from the described project it becomes clear that with relative few hydrological data a full operational FFS can be made. All sub basins are modelled as a 1-dimensional rainfall-runoff model, which results in basin covered discharge input for the hydraulic model. In the end, the general conclusion can made that one should be pragmatic and use the data that is available.
- At the moment of writing this article the Flood Forecasting System for the Maritsa and Tundzha River has been operational and running since it was installed in November 2008. It indicates that a Flood Forecasting System is made very robust, using second order and third order data to replace first order data (or even second order) when it is not available. In this way the flow of input data for forecasting water levels is continuously. Also the model is set-up in such a way that it ensures stability in different hydrological conditions.
- The set up of the DET proved to be very useful in order to combine existing data infrastructure with the new FFS and to manage the complete data flow, as is shown in figure 10.

Recommendations

The recommendations that are given here are divided in technical related recommendations to improve the Flood Forecasting System and recommendations concerning the framework of flood risk reduction.

Technical recommendations

- The accuracy of hydrological and meteorological data has impact on the forecasted water level. While data is used both for calibrating hydrological and hydraulic models as for input for the Flood Forecasting System, the recommendation is made to use accurate measured data.
- Within the catchments of the Maritsa and Tundzha several reservoirs are situated in the upstream part. The retention of reservoirs and its operation rules influence the outflow from the sub-basin towards the main river and with that the water levels. When information about the operating rules is not available and the outflow is used from the rainfall runoff model (instead of measured time serie), the calculated outflow might differ with the real outflow. Therefore the recommendation is made to use operational rules as much as possible. Besides, when using forecasted meteorological forecasts in reservoir management the lead-time could be increased. This means there is enough time to create more retention capacity in the reservoir before a flood arrives.
- Concerning our flood forecasting system we can conclude the following: The flood forecasting system predicted a flood in the village of Elhovo in February of this year, but the flood was predicted 1,5 days too early and the maximum flood level was forecasted higher than measured. Floods did occur a day later in Elhovo. The picture below shows the forecasted and measured water level at 12 February. The February 2010 floods were the first since the system was installed and operational. This experience should be used to further optimize the flood forecasting system.

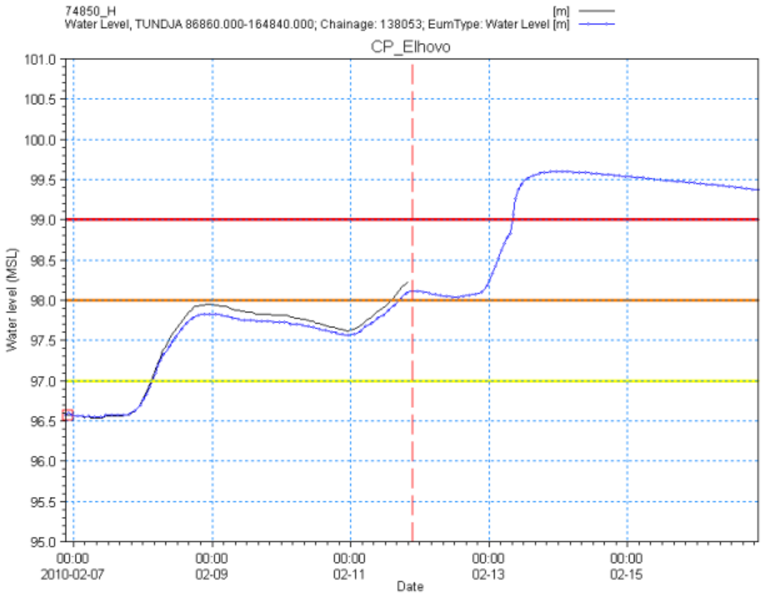

Figure 14 Forecast bulletin of February 2010 flood

Flood risk reduction

- To reduce flood risk and improve preparedness and awareness of all actors in flood prone situations, flood mapping is a well-known non-structural measure in flood management. Flood mapping constitutes even a major part in the EU Flood Directive (EU Flood Directive, 2007). All kind of types of flood maps can be distinguished:
  - Flood extent map;
  - Flood hazard map;
  - Flood damage map;
  - Flood risk maps.

  Within the project flood extent maps are derived based on stationary situation with a certain return period (see textbox 3 and figure 15). These potential flood maps are based on worse case scenarios without accounting the dynamic character of a flood wave. The recommendation is made to provide, besides potential flood maps, flood maps for high water periods detected by the Flood Forecasting System based on non-stationary, real time measured hydrological and meteorological data. The volume due to overtopping of the embankments should be combined with a 2D model of the floodplain in order to calculate more realistic inundation depths.

- In 2005 the large inundation upstream Plovdiv, prevented Maritsa from overtopping the dikes in the city. If there was a hydraulic model at that time, the effect of the upstream inundations could by simulated by lowering the embankments in the model. The recommendation is therefore made to use the water management model with the information from the Flood Forecasting System about a forecasted high water period in order to simulate and analyze particular mitigation measure.

> The output data for the high water levels from the hydraulic modelling can be integrated in GIS environment. GIS played a vital role. It was used for data preparation, data unification, data visualization and, most important, for data modelling within the ArcView Spatial Analyst extension. Using different interpolation techniques grid of water surface is constructed. The water surface is compared with DEM and the result is a flood map. The map provides clear and easy for understanding information of the depth and the extent of the inundated areas with a specified return period.
> Highly accurate Digital Elevation Model (DEM) is required when developing flood maps. Obviously the more accurate the DEM, the more accurate the flood map is. For flood mapping was used DEM with pixel size 10X10 m. From topographic maps in scale 1: 5 000 were manually digitalized contours and points within the flood plain area. The DEM was prepared using TOPOGRID tool in ArcGIS Workstation. The assessment of the vertical accuracy was made using the elevation values from the measured cross sections. Estimated accuracy is around 1.5 m. The maximum water levels are calculated along the rivers for the different hydrological scenarios. From longitudinal profile the flooded area is selected. The results with water levels are exported in ASCII format and converted in ArcGIS in a grid. The resulted grid of the water surface is only for the extent of the cross-sections used in hydraulic model.

Textbox 3 Flood maps

- The FFS that was built in Bulgaria uses state of the art software and methodologies. However in order to be used effectively the flood crisis organization should be clear. The project showed that overlapping tasks and responsibilities of stakeholders obstruct efficient implementation of a FFS. During the project boundary conditions were defined as concrete and strict as possible, in order not to be influenced by unclear tasks and responsibilities within the flood crisis organization. However it is strongly recommended to clarify and define a crisis organization before implementing a flood forecasting system, especially when alert and forecast dissemination is part of the system.

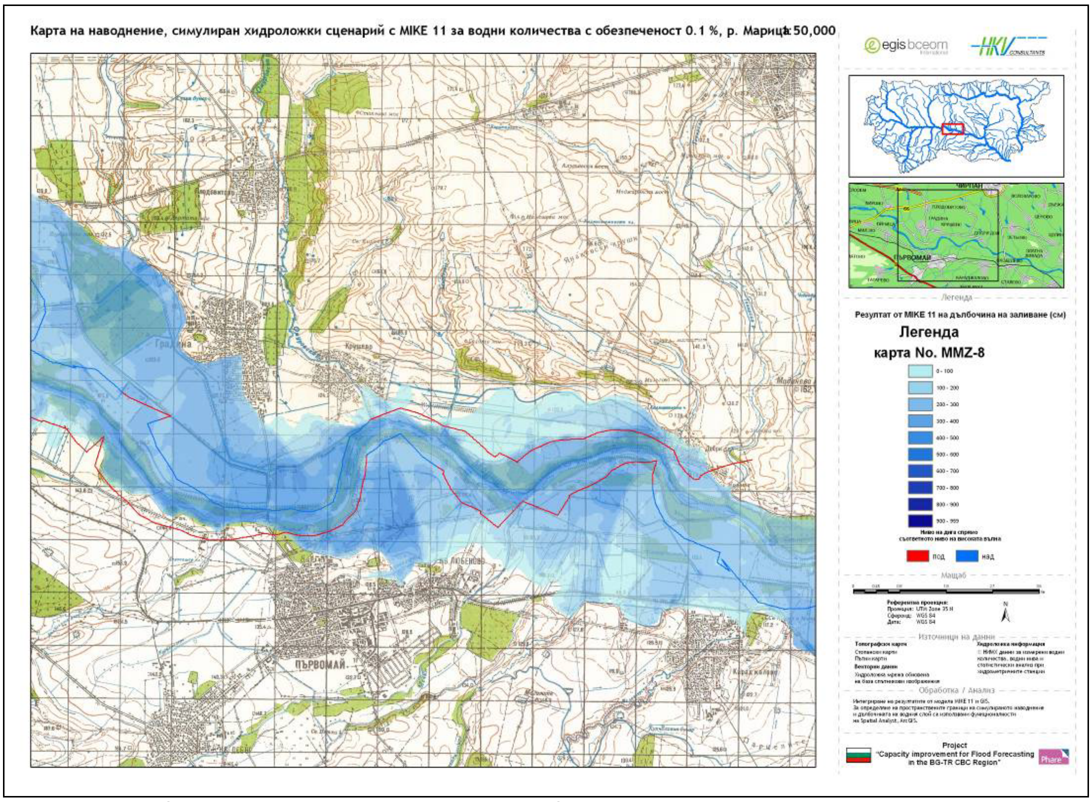

Figure 15 Potential flood map presented propagation of the max water discharge with 1000 years return period on Maritsa River at Parvomay. Flooded area is put over map in scale 1: 50 000.

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