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Application of the HSPF Model for Flood Simulation with Analysis of the Results in Terms of Monitoring Uncertainties /Case Study of the Lesnovska River, Bulgaria/

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Abstract: Floods are amongst the most damaging natural disasters worldwide. The new EU Floods Directive and the implementation of the EU Adaptation Green Paper will require improving of the flood-related research. In this study, the HSPF model was applied to simulate and analyze a very significant and unexpected flood occurred in 2005 along the Lesnovska River, a right tributary of the Iskar mainstream in the western part of Bulgaria. The difference between the simulated and the measured flood volumes was found very high and equal to 130% for the flood of 2005, while percent differences of 25-33% were observed for the seasonal, annual and low flow distribution. These results were compared with an application of the same model for another part of the river system and another flood event in order to find explanation of the discrepancies. The monitoring uncertainties are discussed to be the main reason of the unsatisfactory model performance for the flood occurred on August 2005. On the basis of the obtained results, the flow was recalculated and the probable values of the peak flow were estimated. The needs of implementation of new monitoring practices and technoquies for better flood event knowledge and modeling are outlined.

Keywords: HSPF Model; Modeling; Flood; Monitoring Uncertainties.

1. INTRODUCTION

Floods are amongst the most damaging natural disasters worldwide. The new EU Floods Directive and the implementation of the EU Adaptation Green Paper will require improving of the flood-related research. In the scope of an EU project, Floodmed, eight models (*HEC-HMS, Vflo, MISD, Mike-drift, TRIMR2D, IMGW, Vidra and HSPF*) were applied in seven European catchments (Greece, Poland, Romania, Germany, Italy, Bulgaria, Serbia) to test the model applicability for flood identification [Ribarova, 2008c]. The models showed different capabilities. Although the simulations could be assessed as successful, some imperfections were noticed. The HEC-HMS could not offer a sufficient simulation of the second peak event in hydrographs with two successive flow peaks proving that antecedent moisture conditions play an important role in hydrograph simulation efficiency. TRIMR2D is suitable to simulate flood inundation if high resolution input data are available. IMGV should be used and the results should be interpreted by experienced hydrologists. The selection of the modeling method and the mean precipitation estimation should be passed with relation to conditions within the catchment as well in neighborhood sub – catchments.

The main common problem in modeling of all flood events was reported to be data availability and accuracy [Ribarova, 2008c]. This reflects to modeling uncertainty and is associated with:

- Lack of detailed rainfall data sets. In many catchments the rainfalls were calculated according to the data from the existing stations and sometimes this number was not adequate, especially where temporal distribution of rainfall greatly vary geographically.
- Lack of detailed soil studies, describing the physical properties of soil types such as texture, hydraulic conductivity, etc. Thus, infiltration was estimated from the geological map of the basin, based simply on general knowledge about the permeability of different formations.
- Errors of measured stages coming from problems related to the equipment maintenance as well as enourmous water quantity during the floods.

In this paper, the results of the application of the HSPF model of the US EPA (Environmental Protection Agency) to simulate and analyze a very significant and unexpected flood occurred in 2005 along the Lesnovska River, a right tributary of the Iskar mainstream in the western part of Bulgaria are reported. The problems of data uncertainties are discussed as well. Furthermore, the paper attempts at using the model results for recalculation of the most likely flood values. The HSPF model has been chosen because of its capability to run at time steps of less than a day, since flood events occur over very short periods, but generate large changes in river flow. In addition, the model was applied successfully for flood identification in other studies [Albek, 2004; Karatzas, 2007; Ribarova et al., 2008a].

2. THE FLOODED AREA OF THE LESNOVSKA RIVER

The Lesnovska River is flowing through the Sofia plain and is predominantly a flat river with total area of 1096 km^2. The catchment area is relatively densely populated with numerous small towns and villages gravitating to the capital Sofia [Gerasimov et al., 1986]. Mountainous and hilly areas surround the valley. The climate is moderate continental with temperatures varying between minus 15^oC in the winters and more than 35^oC in the summers. The average annual precipitation is 832 mm. Snowfalls are common in winter and snowmelt contributes to the high flows is in the spring. The high flows in the other seasons are due to the precipitations only.

Extreme flood events were registered in the Lesnovska river watershed, at the Dolni Bogrov Gauge station (North Latitude 4733833.102; East Longitude 212859.780), on 5th of August and 6th of August, 2005 (Figure 1). The average daily flows were reported to be 449.8 m^3/s and 403.0 m^3/s respectively.

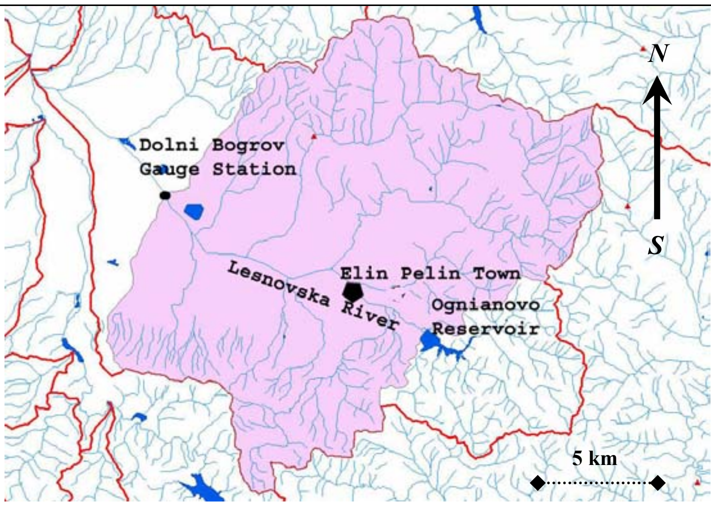

Figure 1. The Lesnovska River watershed with the modelled area between the Ognianovo Reservoir and the Dolni Bogrov Village

Figure 2 visualises the average daily flow for Lesnovska river in August, 2005, compared with the average long term yearly flow of 3.290 m^3s^{-1} for the period 1961-2006 [National Institute of Meteorology and Hydrology, 2005]. The monthly average flow in August, 2005 was more than 100 times higher than the typical average August flow of previous years. This flood event destroyed the life of local people and caused significant infrastructural and agricultural damages.

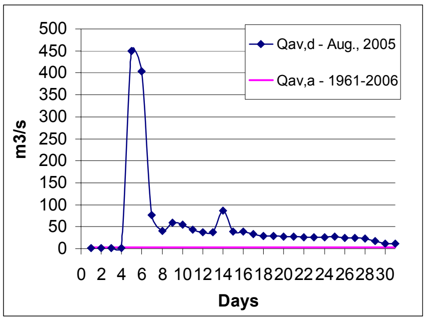

Figure 2. Average daily flows in August 2005 for the Lesnovska river at Dolni Bogrov compared to the average long term yearly flow [Ribarova et al, 2008b]

3. APPLICATION OF THE HSPF MODEL

The HSPF model simulates the time response of the watershed based on hydrological mass balances integrating point and non-point sources [Duda, et al., 2001]. The HSPF model requires two types of data: GIS based data describing the studied watershed and daily hydrological and meteorological time series. The HSPF model was created for the BASINS system [Russel et al., 2003]. It was successfully applied by the research group for modeling of the river run off and quantity at normal climate conditions as well as for simulation of the first flood event after dry summer period [Ninov et al., 2004; Ribarova et al., 2005; Ribarova et al., 2008a, b].

The HSPF model was used to simulate the daily flows at the equipped river section of Dolni Bogrov for the period 2003-2005. The calibration of the model for the Lesnovska River was based on the collected meteorological, hydrological and GIS data for the period 2003-2004. The model was verified for year 2005 when also an extreme flood event occurred in August. The hydrology calibration process follows three subsequent steps: adjustment of the annual trends and water balances, seasonal discrepancies and high and low flows distributions (including stormy periods). The water balances were calculated by estimating the volume of the water passing through the reach according to the hydrometric station (observed data). They were compared to the output volume simulated by the HSPF model. The losses in the watershed were accounted assessing the flow paths, the evapotranspiration and the infiltration. The model uses numerous calibration parameters: functions of the soil; climate; topography; vegetation cover; land use; and geology conditions [Ribarova et al., 2008a, b]. Table 1 shows the values selected for the main hydrological parameters for the Lesnovska river basin.

Table 1. Lesnovska River basin: calibration parameters values for the HSPF model

Parameter	Definition	Units	Values
LZSN	Lower zone nominal storage	inch	9
INFILT	Index to the infiltration capacity of the soil	inch/hr	0.01-0.20
SLSUR	Slope of the assumed overland flow plane	-	0.001
KVARY	Variable groundwater recession	1/inch	0
AGWRC	Base groundwater recession	-	0.995
DEEPFR	Fraction of GW inflow to deep recharge	-	0.35
BASETP	Fraction of remaining ET from baseflow	-	0.20
AGWETP	Fraction of remaining ET from active GW	-	0
CEPSC	Interception storage capacity	inches	0.12
UZSN	Upper zone nominal soil moisture storage	inches	2

During the calibration phase, different scenarios were examined with the aim of reducing discrepancies in the annual water balance and in the seasonal and high/low flow distribution adjustment. The simulation results are shown in Figure 3. Because of the very high peak of the flow on 5^{th} and 6^{th} August, 2005 the curves at the bottom are "crushed". Therefore, the lower flow range (less than 50 m^3/s) is visualised in Figure 4 for better explicitness.

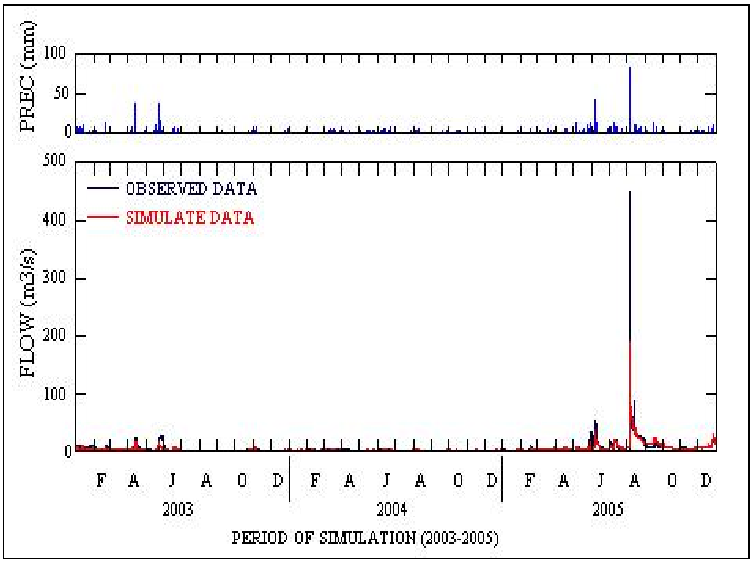

Figure 3. Observed and simulated daily flows and precipitation at Dolni Bogrov Gauge Station – Lesnovska River

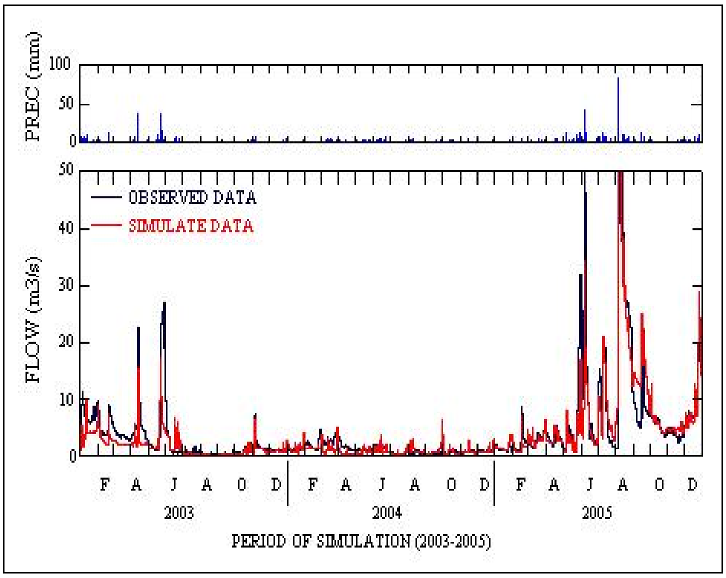

Figure 4. Low-range (less than 50 m^3/s): observed and simulated daily flows and precipitation at Dolni Bogrov Gauge Station – Lesnovska River

According to the calculations (Table 2) the results for the annual balance, seasonal discrepancies and the low flows distribution for the Lesnovska River can be assessed with the absolute volume errors approximately between 1/4 and 1/3 (or 25% to 33%, respectively). Similar are the results for the calibration and the verification periods assessing them as satisfactory with a good fit for the two periods (Table 2). However, the results for the flood peak simulations are not satisfactory – the simulated flow is 130% less than the observed one (Table 2).

Table 2. Annual water balance, seasonal water balance, highest and lowest water balance – Lesnovska River (2003-2005)

Period	Observed flow (m^3)	Simulated flow (m^3)	Absolute volume error (%)
Total period	444 956 588	353 381 547	-25.9
Period of calibration	131 935 095	96 749 975	- 28.9
Period of verification	313 021 464	256 631 572	- 22.0
Winter seasons	53 954 197	40 492 222	-33.2
Summer seasons	213 612 211	159 207 228	-34.2
Sum of lowest flows (Aug-Sept 2003)	1 778 969	1 431 006	-24.3
Sum of highest flows (5/8/05-8/8/05)	88 923 980	38 564 720	-130.0

There are two possible explanations for the high discrepancy between the measured and the simulated flood data: 1) modelling problems – HSPF model is not capable to account for high flood peaks; 2) monitoring problems - objective difficulties of the hydrological and precipitation monitoring for the flood period and uncertainty of the information. We consider that in the case of Lesnovska river flood event, the second explanation is more likely. On one hand, the past experience with the HSPF model shows good results for high flows simulations dealing with reliable hydrological information [Ribarova et al., 2008a]. On the other hand, during the studied flood event, a large area around and within the village of Dolni Bogrov was covered with slowly moving and possibly even stagnant water, which was most likely added to the measured flow. For this reason, some regional experts doubt the reliability of the existing hydrological information.

The research group had applied previously HSPF model successfully for the Upper Iskar River, located upstream of the Lesnovska tributary. Both watersheds have similar physical-geographic and basic hydrological characteristics. The used calibration parameters have the same or close values [Ninov et al., 2004]. Figure 5 presents the simulated and observed flows of Upper Iskar River for the first flood event after summer period, happened in November, 20004.

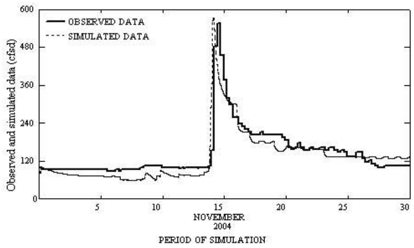

Figure 5. Observed and simulated hourly flows for the flood event in Upper Iskar River in November, 2004 [Ribarova et al., 2008a]

This figure shows clearly the HSPF model simulated quite satisfactory another studied flood event. It gives us confidence to state that the HSPF modeling revealed the uncertainty of the observed flood flows during the studied period, in August 2005 and arouses the question for identification of the flood monitoring problems and the needs of implementation of new practices and technoquies [Ribarova, et al., 2008b].

4. IDENTIFICATION OF FLOOD MONITORING PROBLEMS

The most serious problem concerning the flood monitoring is of hydrometric nature. During the floods the river flows go out of the river beds covering parts of the terraces and valleys around the rivers. The usual measurements of water levels sometimes become impossible due to inundated or inapproachable stations. The effect of floods may augment if dikes and dams are broken. The hydrological characteristics of the floods have a temporal and spatial changeability linked to the changeability of the originating factors as: precipitation intensity and continuity, diversity of their spatial distribution, geographic and topographic conditions in the affected watersheds, level of urbanization, etc. [Gerasimov et al., 1992]. Some indirect approaches are applied for flood events to determine the hydrological elements, such as: the usage of the traces on the banks, trees and buildings showing the highest water level during the floods; determination of river bed profiles before and after the flood; usage of hydraulic formulas to assess flow velocities and etc. All these indirect approaches impact on the quality of hydrologic information during the floods and sometimes increase significantly the uncertainty of the information.

Another problem concerning flood monitoring is the frequency of the measurements. The usage of automatic stations can not guarantee the regular and precise information in short intervals. Serious damages and failure (stopping) of the automated stations, located nearby the river beds, are often before the highest pick of the flood.

The data from the State monitoring hydrological network of the National Institute of Meteorology and Hydrology, even correct, reflect the situation in a narrow river sector and could not be representative for the whole damaged zone when the disaster is enormous and spreads over a big area. Uncertainties related to stage-discharge relationships for high stage values are also a common problem. In this case the network information has to be obligatory enriched with expedition observation and measurements.

The uncertain observations for hydrological data and the unreliable flood informational input in the model (as is the case of Lesnovska River flood, August 2005) show that there is a need for implementation of new monitoring practices and techniques for better flood event knowledge and modeling. There are not commonly accepted opinions or proposals how to cope with these problems bringing up uncertain hydrological information, as well as what practices can be applied to guarantee the reliable monitoring information. The modern remote methods give the most complete picture for the real flood distribution of the affected area – photography in the optic, infra-red and supersonic part of the electromagnetic specter of frequencies using planes, helicopters or cosmic satellites. Unfortunately these methods are expensive and are still not widely spread. Using a dense automatic stations network with frequent, in-time information is technically feasible and very useful. The cheapest way remains the expedition observations during the flood with all risks to add a stagnate water to the mainstream increasing the real running volume during the flood, as perhaps was the case of the Lesnovska River, in August 2005.

5. RECALCULATION OF THE PROBABLE FLOWS DURING AUGUST 2005 FLOOD

We have discussed above that most likely the measured values of the flood event in August 2005 are not correct. The exact uncertainty of observed flows due to measurement errors is very difficult to be assessed. The measurements were done in extraordinary conditions for a relatively short period. The river flows overflowed the bed and banks, covering the nearby fields and running trough the streets of the urbanized territories, shaping areas with stagnant water or slowly moving currents. Some places were dangerous to be approached. Years after disaster we could only rely on other methods, as hydrological models usage, to assess quality of the observed flood information.

We suggest using the results of the HSPF modelling for rough assessment and recalculation of the probable flood flows of Lesnovska River. The model calculates the annual, seasonal and low flows balances approximately 25% to 33% less than the observed ones, except for the period of the flood (5-6 August, 2005), when this value is 130% (Table 2). If we accept that in principal the HSPF model calculates any flood values correctly, we may expect that for the case of Lesnovska river the most probable values of the flood flow would be also 25% to 33% higher than the simulated ones (as for all other data during the 3 years calibration and verification period). Of course, this conclusion, based on the HSPF model results interpretation, can not be strictly proven especially several years after the disaster. Table 3 shows the observed and simulated daily highest flows and those increased with

25% and 33%, outlining the probable range of the real running daily flood pick. The most probable values of the daily highest peaks are calculated to be between 237.9 and 253.1 m^3/s.

Table 3. Observed, simulated and probable highest daily peaks during the flood 5 – 6 August 2005 in m^3/s – Lesnovska River at Dolni Bogrov Station

Flow	Values
Observed daily highest peak	449.78
Simulated daily highest peak	190.3
Simulated daily highest peak increased with 25%	237.9
Simulated daily highest peak increased with 33%	253.1
Most likely daily flood peaks	237.9 – 253.1

Figure 6 visualizes the range where the real daily highest peaks are most likely to be disposed during the flood occurred on August 2005. The presented boundaries are based only on the absolute volume error of the annual, seasonal and extreme balances between simulated and observed data and have a tentative character. However, the study is a step towards the clarification of the real picture of the flood when there is uncertain, probably strongly exaggerated, monitoring hydrological information.

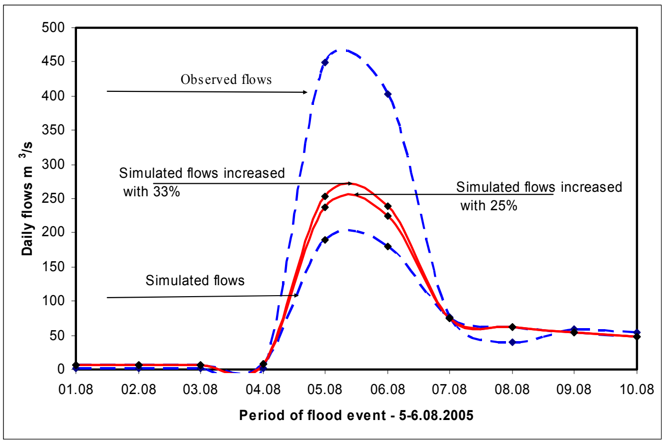

Figure 6. Range of the probable daily highest peak during the flood in 5-6 August 2005 at the Dolni Bogrov Gauge Station - Lesnovska River

6. CONCLUSIONS

The presented investigation reveals the uncertainty of the hydrological information during the extraordinary flood in August 2005 for the Lesnovska River case study. Although being unique one, this event represents some common monitoring problems concerning the flood disasters. A possible solution for overcoming of flood data uncertainty is a combination of the classical methods with modern remote approaches. Through improvement of the quality of the monitoring information during the floods we can enhance our knowledge of the events in order to better simulate and forecast them. Introducing the modern remote approaches as operational practices in the case of extreme flood events would improve the hydrological information and would help the modeling and better forecasting of the disasters. The main problem of their application spreading is the increased financial expense for techniques, staff and organization, as well as the necessary inter-institutional cooperation and agreements.

The application of comprehensive hydrological models, as the HSPF model, helps us not only to identify periods with uncertain information but to try to restore the probable real flows running during the floods.

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