DEVELOPMENT OF A FLOOD ALARM AND FORECASTING SYSTEM ON THE UPPER-TISZA RIVER BASIN

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Abstract: The Tisza river above the Tokaj section collects its water from four countries (Ukraine, Romania, Slovakia, Hungary). Rapid changes in water level have always been a characteristic feature of the river. Because of its flood-hydrological and hydro-meteorological characteristics rapid, high and fierce floods can be expected in any time of the year along the Upper-Tisza. The rise of the water level can reach the critical height within 12-36 hours along the river section in Hungary. The ever-growing risk of flood sets high level of demand for data- and information collection, storage and processing besides hydrological forecasting which can be completed with effective international cooperation only. The two main targets of the coordinated development of the flood protection system have to be: the time-lead of flood forecasts and that of information dissemination has to be increased; the accuracy and reliability of water level and discharge forecasts have to be improved. In our study we demonstrate our experiences gained during the processing, testing and calibrating of the various models above, moreover we set the development aims required by the application of up-to-date, more complex models, and the possibilities of the international cooperation.
Keywords: flood management, hydrological forecast, hydrological measuring network, radar meteorology, lead-time, numerical regression, rainfall/runoff model, hydrodynamic model.

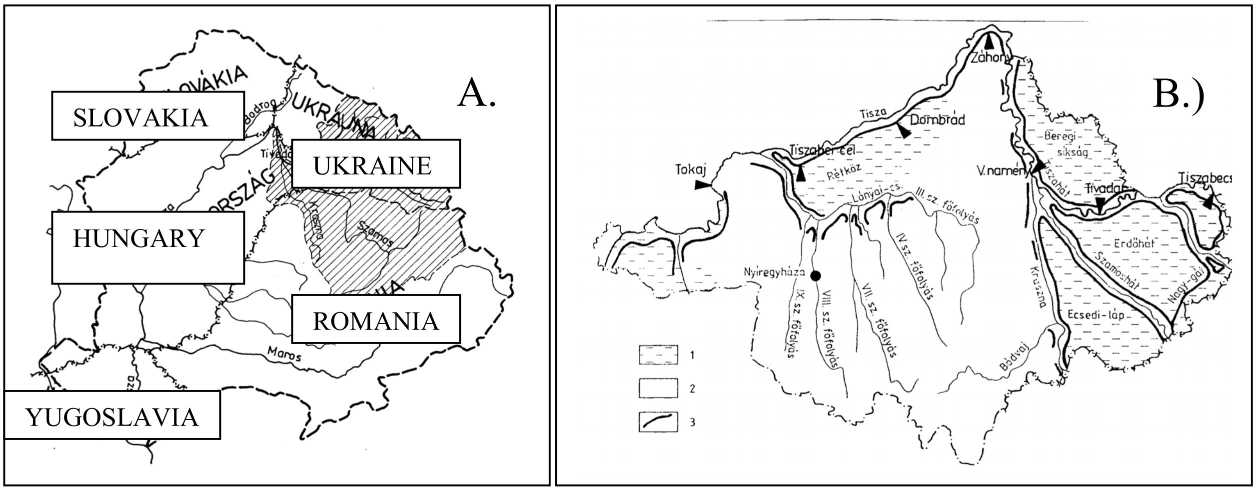

Fig. 1. The geographical location of the Upper-Tisza the catchment area (A). The Hungarian section of the River Tisza and its tributaries, main water gauges on the Tisza (B).

1. Hydrological, technical and organisational conditions in preparation of hydrological forecasts

The hydrological basin of the River Tisza with a territory of 157.200 km^2 expands to 5 countries, however only 4 countries share the catchment area above Tokaj. These four countries are: Ukraine (26,0 %), Romania (45.2 %), Slovakia (14.7 %) and Hungary (14.1 %). Because of their mountainous features, higher precipitation and runoff, the catchment areas in Ukraine, Romania and Slovakia contribute 96 % to the mean annual runoff, while Hungary contributes hardly over 4 %. Despite this fact, the total mass of water arrives here, uniting the waters of the Rivers Upper-Tisza, Tur, Szamos and Bodrog. The hydrological basin in Hungary is located in the north-east of the country, north of the Hungarian Plain, at two sections forming the frontier between Hungary and Ukraine, with a total length of 208 km.

While the catchments areas in Ukraine, Romania and Slovakia are mainly mountainous and hilly areas, the Hungarian basin is plain with low gradient, slow rivers, closed in between high protective dikes. The length of the dikes along the Upper-Tisza tributaries in Hungary is nearly 700 km. The vast majority of floods (app. 94%) in the Carpathian Basin are caused by macro- or micro scaled cyclone systems (perhaps coinciding with snow melting), while only 7% is primarily caused by rapid snow melting due to zonal warm advection.

The catchment area of the Upper-Tisza is located south, or southwest of the mountain ridge. As a consequence, the axis of the southwest, northeast route of warm, wet air is nearly perpendicular to the mountain range. Therefore the amount of precipitation is the highest in the northeastern part of the Carpathian Mountains, in the area where the springs of the river Tisza are located. (Fig.2).

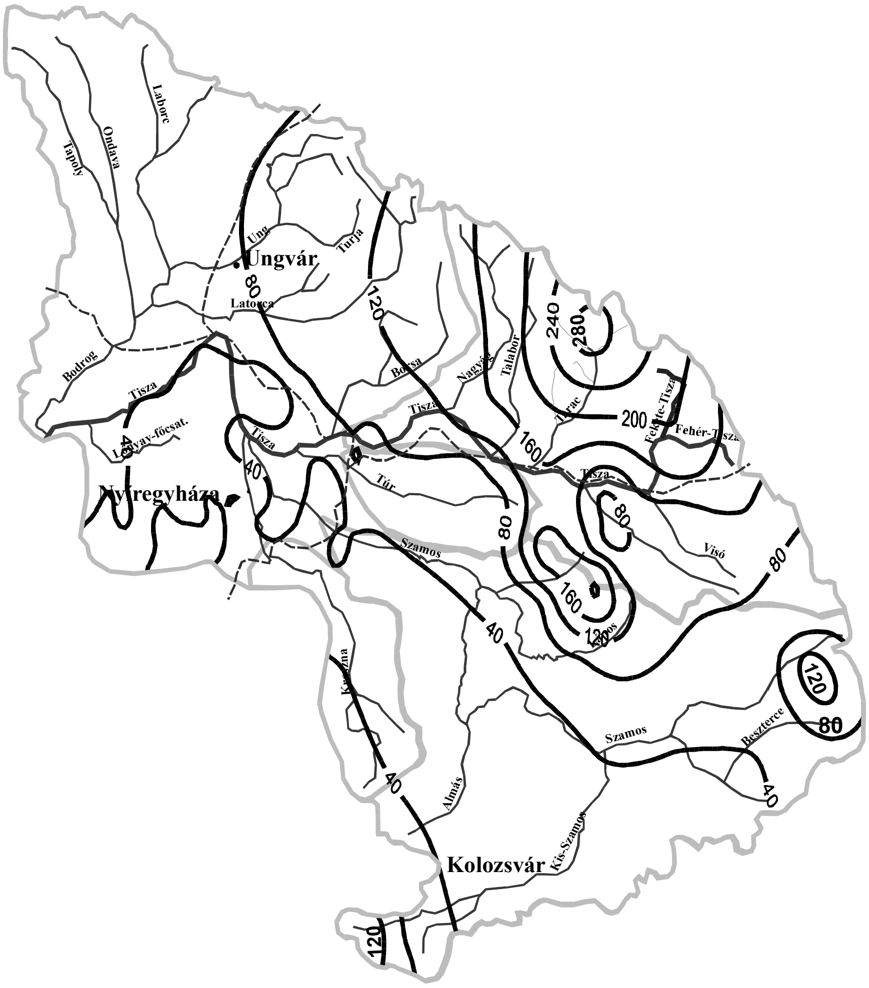

Figure 2. Rainfall distribution on 3-5 March 2002

High flood waves can form in nearly any month of the year (Figure 3.) The frequency of peak stages is the highest in March on the Upper-Tisza (17-22 %), the second highest is in April (13-16 %).

In August and September it is exceptional to have peak water, however in November and December the frequency exceeds 10 % again. Summarizing the results it can be concluded that during the cold period of November-April, when the flood waves form as a joint result of snow melting and rains, 77-80 % of the annual peak water stages occurred during this period (*Konecsny* 2000).

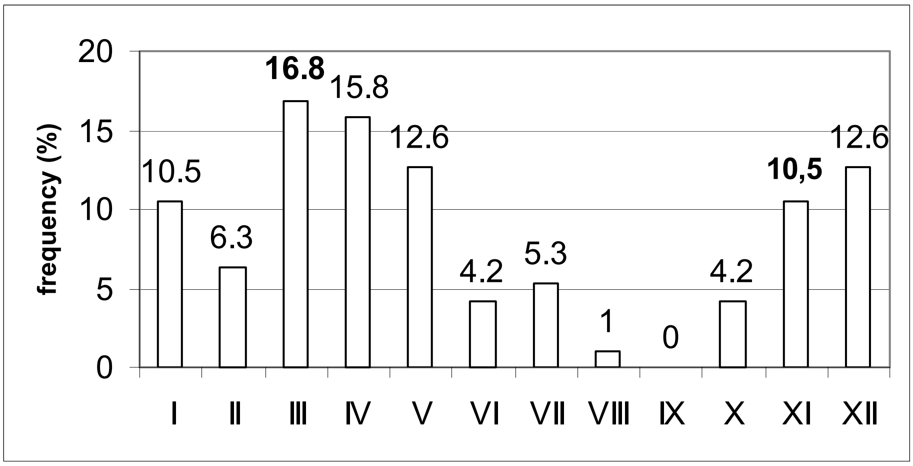

Figure 3. Frequency of occurrence of the annual maximum water stage within the year (Tisza – Tivadar)

At mountain sections flood peaks are formed within hours following the end of precipitation. Accumulation time is short, which was well demonstrated by the huge flood in November 1998 (Fig. 4.). At that time, between 2 - 5 November on the mountain sections of the river the flood peaks formed in 24-28 hour after the beginning of the rain. The intensity of water level rise can be as high as 20-40 cm/hour. During the flood waves the rise of the water stage can reach 10-11 meter per 20-40 hours on flatland river sections. Similarly big and fierce floods took place in March 2001, which was accompanied by several dike breaches.

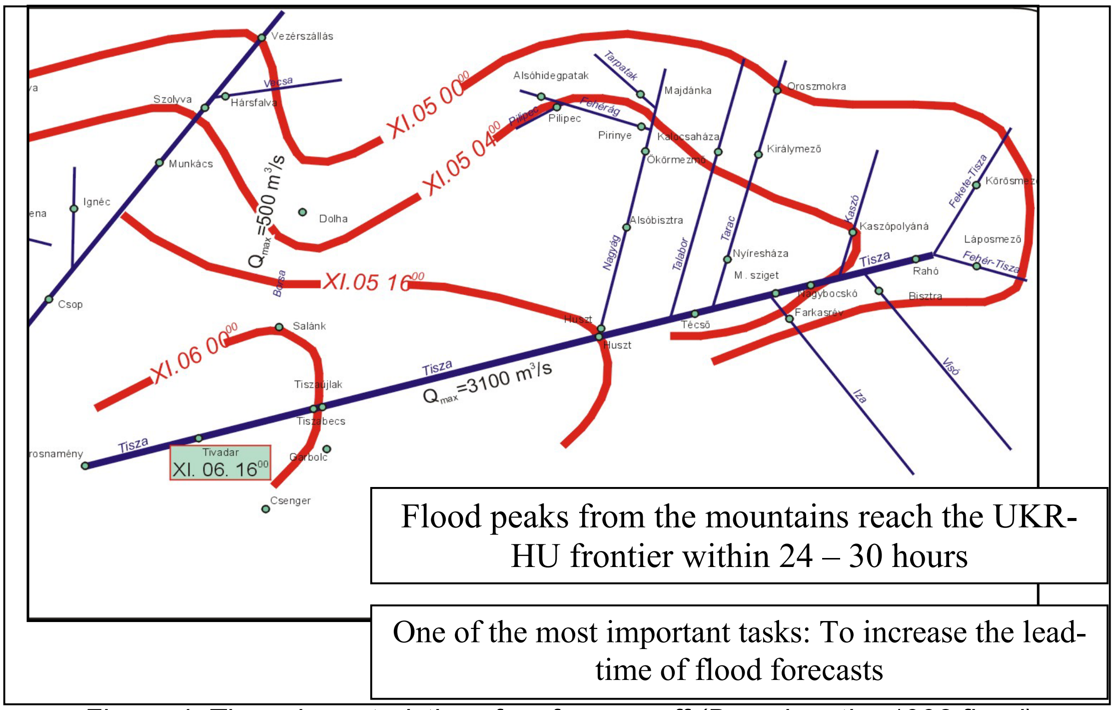

Figure 4. Time characteristics of surface runoff (Based on the 1998 flood)

2. Principles of the medium-term development of flood monitoring and forecasting

The above characteristics clearly show that the highest possible increase of the lead-time is crucial from flood prevention point of view. Because of the listed hydrological characteristics the following have special role in increasing the lead-time:

- on-line remote sensing network;
- meteorological radars;

- information provided by meteorological satellites;
- applying the results of short- and long-term quantitative precipitation forecasts;

In this paragraph we evaluate the present state of the above and gives proposals for the direction and specific content of development. With regard to the division of the catchment by state borders, the analysis was expanded to areas over the borders too. Requirements and questions of Ukraine about development are formulated here. One of the conclusions is, that successful flood forecasting on the Ukrainian section of the Upper-Tisza is only possible by a cooperative, internationally unified and co-coordinated monitoring system.

2.1. An overview of the present situation

The first Ukrainian (Soviet) plans for automation of measuring were prepared between 1986-90 in the framework of a Hungarian-Soviet technical-scientific cooperation. Based on this plan a Ukrainian automation development plan was prepared, and then depending on financial sources the implementation began in the mid-1990s.

- The central building of the system was constructed in Uzhgorod in 1999. In the framework of a Hungarian – Ukrainian collaboration, establishment of an automatic data transfer system for flood forecasting commenced, financed by Hungarian government grant. Accomplished major Hungarian-Ukrainian developments are as below.
    - Installing structured computer network in the central building of the Trans-Carpathian Water Directorate;
    - Creating hydrological remote data measuring network containing one center and 2 stations;
    - Constructing the backbone of a UHF network capable of voice – and data transfer, covering the whole Trans-Carpathian region.
    - In 2002-2003 twelve new automatic stations will be constructed in the catchment sectors in Ukraine with Hungarian government aid;

Other development in progress in the Ukrainian territory of the Tisza river basin is as below.

- Assisted by Danish government grant (financed by Dancee, assisted by DHI) the implementation of a Danish-Slovak-Ukrainian project concerning the catchment area of the Bodrog is in progress.
- As a part of this project 14 hydrological stations and 2 automatic water quality stations are planned in the catchment area of the Uzh. The designs of these stations have not been prepared yet.
- According to plans, two stations will be automated with Tacis assistance. The stations have not been selected and designs have not been prepared yet.
- USAID through ULRMC (Ukrainian Land and Resource Management Center) is ready to assist the installation of two stations. The designs are completed for these. Apparently, the planned equipment operates on different theoretical bases from those already constructed.
- UNDP is aiming at establishing a sustainable development project in the whole Tisza valley, the scope of which is larger than flood control.

In adjacent catchment areas:

- **In Romania** - 38 stations are planned in the catchment of the Upper-Tisza on PHARE funds (Viseu, Iza, Tur)
- **In Hungary** automation of the ground station network has a long, 30-year history. Information technology components of the system have been updated four times during the three decades. The present monitoring system includes 14 stations and a center. The Hungarian and Ukrainian systems form actually one large unit with two sub-centers and are linked by a microwave channel. Automation of further 5 – 8 stations will take place during the next three years in Hungary

- **In Slovakia** there are altogether 4 automatic stations (MARS-5 type) in the catchment of the Bodrog, however according to plans 40 stations will be automated by 2010 (POVAPSYS Program).

Radar-meteorology system:

- At present there are two meteorological radars in the region in Kosice and in Nyiregyhaza-Napkor. Both of them are out-of-date Soviet products, MRL-5 type.
- Hydrological institutions in Ukraine only get the data of the Nyiregyhaza-Napkor radar regularly. These too are transferred by the direct microwave link between Nyiregyhaza and Uzhgorod. Data transferred from Hungary is processed and displayed by Hungarian programs.
- The Nyiregyhaza-Napkor radar and data processing programs linked to it will be changed in 2002-2003. Data of the new radar will be available for Ukraine too.
- Romania is planning to install a new radar station with PHARE aid, located above 1000 m on a hill of Ignis near Baia Mare. This radar will cover those parts of the catchment in Ukraine, which are not properly covered by the radar in Hungary.

Meteorological services:

- METEOSAT satellite images function as supplementary information sources in the flood information and forecasting system. As experience proves, they supplement short-and long-term precipitation forecasts and data of the meteorological radar very well, and assist the issue of hydrological warnings and continuous information release during floods on the Upper-Tisza
- The flood protection center in Uzhgorod receives data from the satellite of Nyiregyhaza.
- The flood protection organizations in Trans-Carpathia besides their own Ukrainian meteorological forecasts use the precipitation forecasts of the meteorological services of Hungary
- The meteorological services of Ukraine do not use the ALADIN forecasting model, running in large centers of Europe.

2.2. Proposed development program for on-line monitoring

Rapid development in electronic data transfer can be expected in the next few years in Ukraine too. Development strategies that enable the system in Ukraine to be connected to the systems in Hungary, Slovakia and Romania have to be applied. However, the systems do not require identical components and functions. Main development strategies proposed are as below (Illes 2001)

- Considering the rapid development of information technology and communication, the backbone of the automated system (centers, data transfer, links) has to be set up in 2-3 years if possible;
- Parallel, coordinated development is necessary for each component of the system;
- Keeping the homogeneity on catchment scale, the Upper-Tisza automated system has to be integrated into the central flood and hydrometeorological information systems of Ukraine.
- The automatic systems of the countries have to be linked by of up-to-date IT equipment. The hardware and software facilities of linking have to be developed locally, according to the specifications of the country.
- The common system has to provide the same services to each participating country.
- Operation has to be continuous, with special attention to hydrological forecasting and reliability.
- The automatic monitoring system should carry out remote sensing and measuring useful for forecasting models.

3. Analysis of the applicability of various hydrological forecasting models

Flood levels in 1998, 1999, 2000 and 2001 exceeded each time the previous record maximums. In less than two and a half years in five flood periods 192 forecasts and hydrometeorological reports were issued.

The basic methodology for hydrological forecasts at the Upper-Tisza Water Directorate was laid in 1957, reviewed in 1972 by VITUKI. These were graphical three variable relationships mostly between water stages. By the end of the 70's the extended length of the observed data series and the new possibilities offered by the development of the computer technology made the introduction of new statistical methods feasible. In this period multivariable regression technics were introduced offering the use of a larger number of independent variables (water stages, rainfall data) as well as experiments with the application of non-linear technics.

Until the March 2001 flood forecasting methods available were as below.

- graphical relationships
- multivariate regression methods
- analysis of similar hystorical floods
- use of forecasts issued by Romanian and Ukrainian institutions upstream

According to the Hungarian Hydrological Regulations the forecast mostly covered the flood peaks (water stages) and their time of occurance. The sections of the Rivers included in the forecasting system were:

- River Tisza: Tiszabecs, Tivadar, Vásárosnamény, Záhony, Dombrád, Tiszabercel
- River Szamos: Csenger
- River Túr: Garbolc
- River Kraszna: Ágerdőmajor.

Before and during the 2001 catasrophic flood most of the forecasts were prepared by the method using multivariate regression calculation first elaborated by Balint and Simon in 1981 and updated in 1988 by Enyedi and Matavovszky. With this method the first real forecast only can be issued after the occurance of the first peaks on the upmost measured tributaries. Although the accuracy and reliability of the forecasts proved to be very good, the lead-time is limited by the physical process. Experience showed that this lead-time in case of section close to the border was hardly enough to mobilize necessary flood fighting forces.

Both the above experience and the new, fast ways of simulating flood progression by new, ever faster computers justified the start of a new development project aiming at working out new ways of future flood forecasting methods. This project lead by the Upper-Tisza Water Directorate started in 2000 and was finished in mid 2001. The project took into account all other national initiatives aiming at improving flood forecasts and one of the most important goals was to increase the lead-time by trying to apply catchment flood simulation models including both rainfall/runoff models and hydrodinamic methods.

4. Rainfall/runoff models

Initiated and co-ordinated by the Upper-Tisza Water Directorate, many Hungarian experts were involved in carrying out several investigations with the aim to compare the applicability of various precipitation forecasts and precipitation radar data and to compare the possible accuracy of water stage/discharge forecasts while using them.

During his investigations, B. Gauzer (2001) compared water stage forecasts prepared with areal mean precipitation forecasts covering the whole catchment area of Tisza upstream Tiszabecs with results, gained from the usage of a modern, grid related precipitation forecasting model (ALADIN). The calculations apply to the Tiszabecs section of the Tisza, in November 1998.

We can conclude from the test runs, that the ALADIN model produced far better results than those based on the mean forecasts, regarding forecasts with one-day lead-time as well as with two-day lead-time. When comparing peak figures the following has to be taken into consideration: the models did not count with the impact of dike breaches in Trans-

Carpathia, without which the peak would have taken place a few hours earlier, with 725 cm water level.

1-DAY FORECASTS OF WATER STAGES WITH THE VITUKI MODEL AT TISZA - TISZABECS, 25 October 1998 - 11 November 1998

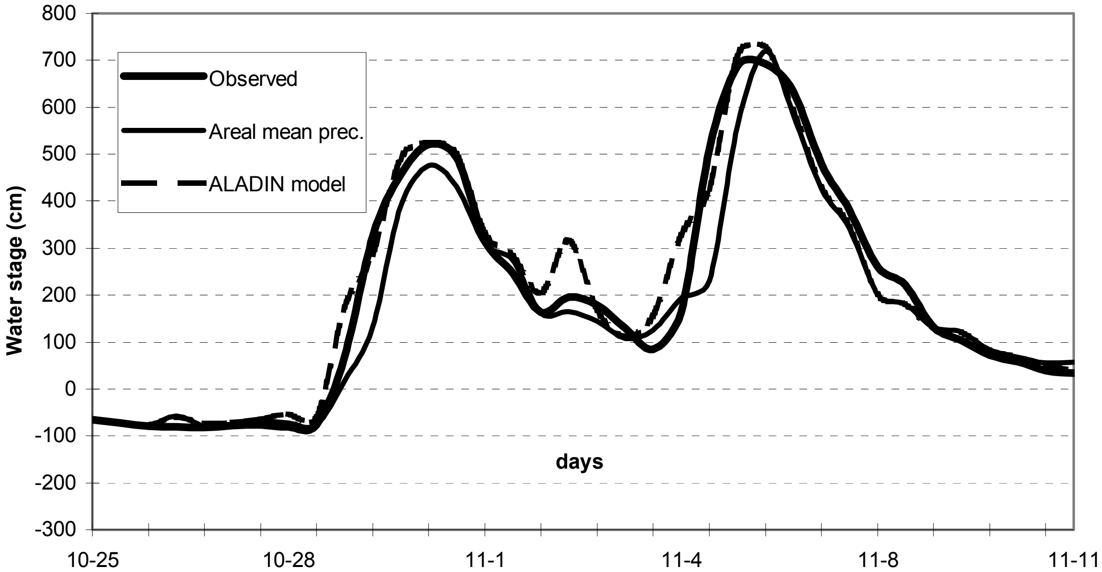

Figure 5. Water stage forecasts with the lumped parameter model

The above model developed by VITUKI is a lumped parameter model with autocorrelated error correction. The other model tested was developed by the Technical University of Budapest and it is a distributed parameter model. In theory a distributed parameter model follows the physical processes more closely, however obtaining proper, reliable and representative parameters is very difficult.

2-DAY FORECASTS OF WATER STAGE AT TISZA - TISZABECS 25. october 1998. - 11. november 1998.

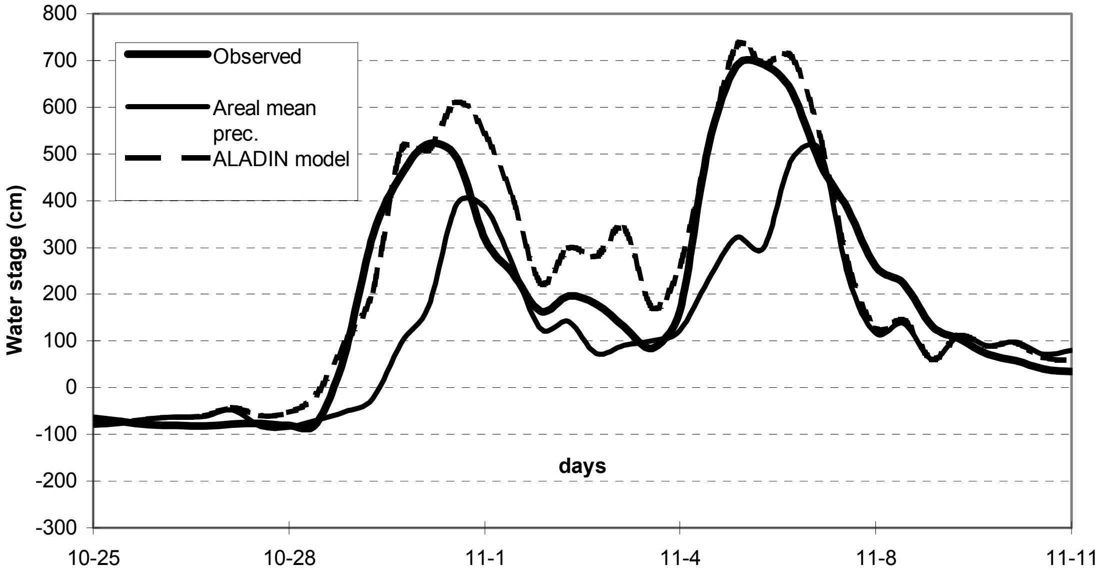

Figure 6. 2-day lumped parameter forecasts

Conclusion

Both models produced promising results and can be expected to be applicable in practice after further development. The errors of the lumped parameter model were smaller because of the auto-correction sub-model.

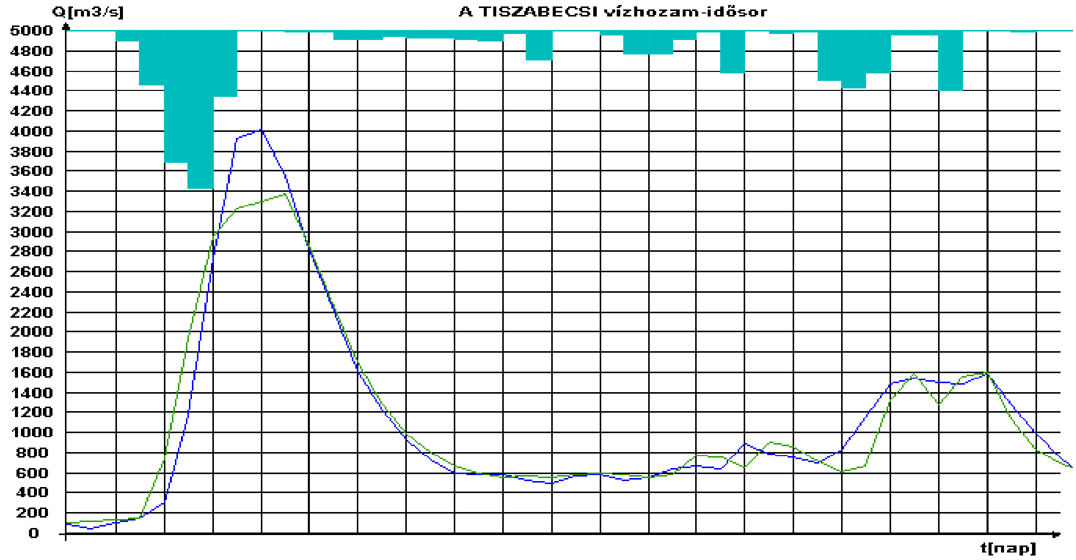

Figure 7. Discharge forecasts with the distributed parameter model (Szabo 2001), based on rainfall forecasts with the Aladin model (blue: measuered, green:forecasted)

5. Flood forecasting with multivariate regression calculation

The main goal of the development of the model was to enhance its capacity and turn it to a really user-friendly, windows based forecasting model. There was no change in the mathematical theory, however the system of the independent and dependent variables follows a new design, the choice between various parameters to be used as independent variables and the approximation of non-linear relations with sectional linear relations is new compared to the old method.

Independent variables are always peak water stages and their time of occurance.

Dependant variables: flood peaks at upper sections simultaneous water stages with flood peaks at various lower sections 6, 12, 24… hour rainfall data at various stations

The biggest change, however, is the extention of the data series, that is the data of all flood hydrographs until the last floods including the year 2000 flood.

Besides the forecasted peaks and their time of occurance the model also selects the five „most similar” hystorical flood hydrographs offering a visual inspection by the hydrologist and help him make a subjective but many times useful evaluation of the process.

Future development needs. Although special care was taken to double check and correct all possible impacts that could have influenced the time series used in the model, at some stations we realized that there was a positive or negative trend in the time series of the errors. It seems a very logical conclusion that flow conditions on the catchment or in the river bed have changed. Therefore an additional method has to be developed to take into account this effect.

6. Forecasting water stages/discharges by hydrodynamic models

On the Upper-Tisza section Balint (1984) made the first experiments with the practical use of hydrodynamic methods for forecasting flood levels and discharges. Because of the limited capacity of computers at that time he had to simplify the Saint-Venant equation, arriving at the so called “Sluice-chain model”. The results on the Vasarosnameny-Záhony section were really promising.

In the present study Koncsos elaborated a model for the Tiszabecs-Tokaj section of the River Tisza based on the one dimensional Saint-Venant equation. Calibration was done on hydrographs gained from 1998 and test forecast were performed for hydrographs of independent time periods.

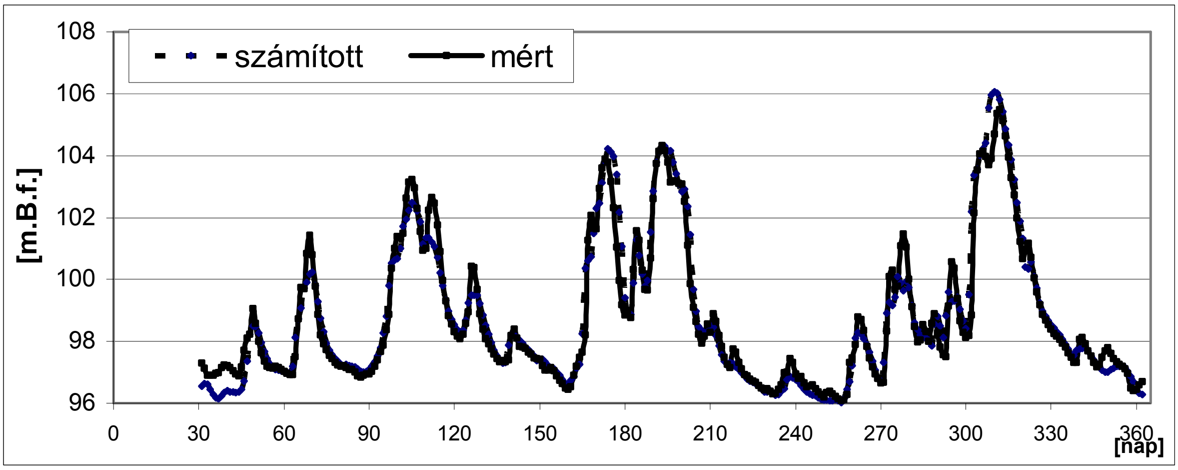

Figure 8. Calculated (- - -) and measured data (-----) at Zahony produces by the hydrodynamic model

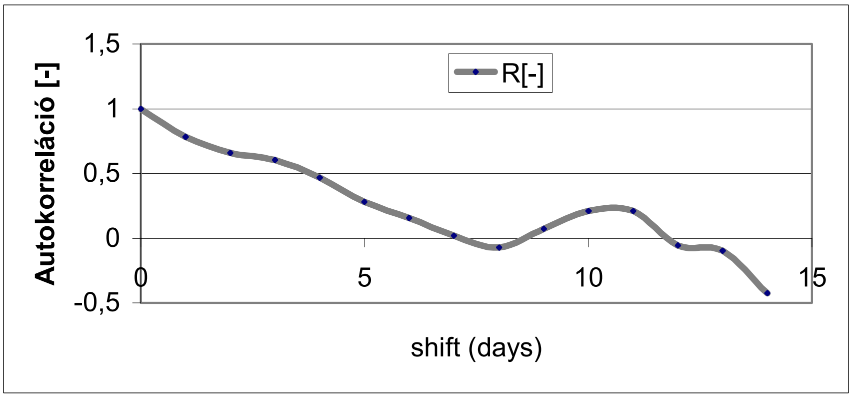

Figure 9. Autocorrelation of the error time series for Fig.8

Athough the forecasts of the peak values gained with the hydrodynamic model are not better than those gained by the regression method, the advantage of the hydrodynamic approach is that it can forecast the total hydrograph. Besides it also can be used for studying various effects of hydraulic structures and even dike breaches. The investigation also revealed the necessity of good and up-to-date topographic surveys of the cross-sections of the river.

Conclusion

Having performed all the above serious research we can conclude that from a scientific point of view the Upper-Tisza Water Directorate today is much more equipped to face the forecasting problems of a new flood. To turn the theoretical knowledge into practical results, however, more and more accurate hydrometeorological data are needed that can only be produced by a denser network, more on-line monitoring stations, observation of new parameters and the use of the system of meteorological radars covering the total basin of the River Tisza. Practical development of the forecasting models should follow a basin wide approach in building up an international modular forecasting system.

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