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HYDROLOGICAL FORECASTS OF DANUBE FLOOD 2013 BY THE HUNGARIAN HYDROLOGICAL FORECASTING SERVICE

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ABSTRACT. – Hydrological forecasts of Danube flood 2013 by the Hungarian Hydrological Forecasting Service. The significant lead time resulting from the use of the OLSER system of the Hungarian Hydrological Forecasting Service is of key importance in making timely preparations for flood defence. Due to continuous improvements to the quantitative meteorological forecast models (primarily the generally used ECMWF model) and the OLSER system over the past years, we have by now reached a point where the previously separately managed flood peak forecasting and continuous forecasting can no longer be interpreted independently. Continuous forecasting taking into account precipitation forecasts and monitoring spatial changes of the complex physics-based concentration process also offers a level of accuracy suitable to identify peak values. The flood wave of June 2013 along the Hungarian Danube section exceeded the ever observed highest high water levels everywhere (except for gauge Mohács). The forecasts prepared by HHFS played a crucial role both in terms of lead time and the forecasted water levels.

Keywords: hydrological forecast, Danube flood 2013, Hungarian Hydrological Forecasting Service, OLSER.

1.The operating method of the hungarian hydrological forecasting service and the structure of its forecasting system

The Hungarian Hydrological Forecasting Service (HHFS) prepares water level forecasts for the key gauges for major Hungarian water courses every day of the year. HHFS primarily uses its own website network (www.hydroinfo.hu) to convey information to users but telephone and email hotlines are also available means of communication.

OLSER, the runoff forecasting and simulation system of the Hungarian Hydrological Forecasting Service, is basically a model system built from modules (building blocks). The models of the individual parts identifiable within the complex system of the runoff process are the functional modules. These can be used to calculate hydrological process parts (e.g. snow accumulation and melting or runoff components) and applied to any user-defined structure of a catchment.

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It must be noted that the Hungarian Hydrological Forecasting Service (HHFS) is not only an organisation regularly operating the forecasting system but also a forecasting service, which issues a forecast every day throughout the year reviewed by qualified staff whose practical experience and up-to-date knowledge are guaranteed by their rotational work schedule. In addition, the forecasting and modelling system used in daily operations is HHFS's own proprietary tool, a rarity in and of itself, which warrants that any fault in any system component can be eliminated almost immediately with help from the staff member on duty (Szöllősi-Nagy, 2009).

The 2013 Danube flood represented a challenge for HHFS members in several aspects:

- After last years' continuous developments, HHFS forecasting system (OLSER) was firstly tested in a real flood situation, therefore a thorough verification process was performed on primary forecast results.
- Since the last historical flood (2006) HHFS was assigned from VITUKI, since 2012 it operates within the General Directorate of Water Management (OVF) with different working conditions, requirements, deadlines and expectations.
- Compared to a significant flood on Tisza river, Danube floods can possibly be relatively less complicated and can have a shorter propagation time, however the 2013 Danube flood with its increased economic effect (especially in Budapest), heightened public interest and attention required a particularly watchful and strict timing forecast activity throughout the flooding event.

Hereinafter HHFS forecasting work in the period 1-17 June 2013 is presented.

2.Hhfs forecasting activity during the flood

Except for a few days in the beginning of the flooding period, HHFS was monitoring meteorological and hydrological events and their evaluation in round the clock duty.

HHFS issued 56 hydrometeorological reports giving detailed summary and analysis of the ongoing and expected meteorological and hydrological situation on the territories affected by the flood. The reports gave an overview on the measured and forecast precipitation amounts as well as on the flood propagation details. In the beginning of the flooding period HHFS's daily report served as a warning, later on expected flood peak values were included in the report giving support to flood defence activity and the public at large. The HHFS's website (www.hydroinfo.hu) and the HIR information system (available only to the professional community) were continuously updated during the whole period, so that users could find the most up-to-date forecast information at all times.

A new product was developed during the flooding period, namely a synthetic map giving a comprehensive presentation of the latest observations and forecasts for the most important gauges along the river. This map was updated and issued about 155 times during the flood event.

3. Issued hhfs forecasts

The OLSER forecasting system developed by HHFS is suitable for modelling a whole spectrum of processes, including snow ablation and melting, interception, evapotranspiration, infiltration, surface runoff and various subsurface flow processes (Gauzer, Bartha, 1999).

The system has a distributed structure both in space and in terms of parameters, as a result of which it can take into account the local slope conditions and exposures, and the soil and vegetation characteristics of the specific areas. The system is driven by weather forecasts for the following six days, thereby creating the opportunity to forecasts processes in their early phases with a comforting lead time and even to issue notices and warnings prior to rainfall.

An analysis of the forecasting scenarios during the evolution of a specific flood wave reveals a number of phases based on the applicable methods and the factors affecting the expected forecasting error. Their characteristics are summarised in *Table 1*.

Using the categories in *Table 1* for the forecasts of HHFS, the following conclusions can be made:

Table 1. The different phases of a flood wave evolution in terms of the forecasting process.

Phase no.	Description	The factor mostly affecting the forecasting error
Phase 1	The meteorological processes causing the flood wave are not yet completed. No or just some precipitation in the catchment. Forecasting relies primarily or mostly on precipitation forecasts.	Precipitation forecast
Phase 2	Most of the precipitation causing the flood wave is on the ground in the catchment so the forecast can rely on the measured values of precipitation. The concentration processes are not yet completed and most of the water has not reached the riverbeds.	Rainfall- runoff (hydrological) model
Phase 3	The concentration process is mostly completed and most of the precipitation is now in the riverbeds.	Flow routing (hydraulic) model

Phase 1: 29 May–3 June 2013

HHFS issued its first Hydrometeorological Report in the morning of May 29, the day before the rainfall arrived. In the first days, HHFS only outlined that the development of a major flood wave was possible. In the report of June 1, HHFS predicted a peak of approx. 800 cm for Nagybajcs and Budapest, a value about 1 meter below the later real peak. However, most of the precipitation was still not on the ground and it was more than 6 days before the peak at Nagybajcs. In the report issued two days later, on June 3, the forecasts for the river section between Nagybajcs and Budapest indicated the peak water level with an error interval of 42–73 cm (1–48 cm when the upper limit of the error interval is applied). With the exception of Nagybajcs, water levels above the earlier HHW were forecast for all gauges that day.

In summary, it can be established that the forecasts of HHFS predicted water levels above alert level 3 even before the rainfall causing the later flood arrived. However, the estimated water levels were significantly lower than the actual peak levels some 4.5–6.5 days later.

Phase 2: 4 June 2013

This period extends from the start of the rainfall until the Danube's peak at Kienstock between 11 p.m. on June 4 and 3 a.m. on June 5. The forecasts at that time were more accurate and even though the peak levels were underestimated by 15–28 cm, the actual values for the river section down to Budapest were, in each case, within the error interval.

In summary of this phase, we can establish that the forecasts of HHFS after the rainfall but still during the concentration process were more accurate in comparison with the previous phase, and the forecast error interval includes the actual peak level values for the river section down to Budapest.

Phase 3: 5–12 June 2013

The majority of the flood wave was already in the riverbed of the Danube during this period. With slightly increasing values up to June 10, the forecasts became increasingly accurate and provided results with sufficient accuracy for all gauge stations.

The forecasts issued on June 10 listed lower peak water levels than before but these were "pushed back up" a day later. The reason behind that was that in the early hours of June 10, the water level stopped increasing at Dunaújváros and the water level time series appeared to be close to peak condition. As the specialists of the Székesfehérvár and the Budapest water directorates reported no extraordinary event, the experts at HHFS considered this situation a somewhat early but, lacking any other information, possible. This "peak" at Dunaújváros significantly lower than expected resulted in lower values in the peak forecasts for the sections downstream. After issuing the forecast, the water level rose and the peak basically stopped at the level forecast earlier. (Note, that there is still no explanation for this phenomenon clearly visible on the water level chart.)

Table 2 indicates the peak- water level forecasts issued for the various dates while *Table 3* illustrates the root-mean-square error of the peak level forecasts issued 1–8 days prior to the actual peak.

Table 2. Summary of the peak water level forecasts issued by the Hungarian Hydrological Forecasting Service

	Forcasted maximum water level (cm)											Observed maximum water level	
Gauge station	2 June	3 June	4 June	5 June	6 June	7 June	8 June	9 June	10 June	11 June	12 June	Water level (cm)	Date
Nagybajcs	840±20	865±20	890±20	890±20	900±10	910±10	-	-	-	-	-	907	7 June 9.00 pm - 8 June 05.00 am
Komárom	780±25	810±25	820±25	820±25	830±10	840±10	845±5	-	-	-	-	945	8 June 05.00 - 11.00 pm
Esztergom	740±25	775±25	785±25	785±25	795±15	805±10	810±10	-	-	-	-	813	9 June 04.00 - 07.00 am
Nagymaros	685±30	715±30	730±30	730±30	740±15	740±15	740±15	752	-	-	-	751	9 June 01.00 - 04.00 pm
Budapest	830±30	860±30	875±30	875±30	885±20	885±20	885±15	885-895	-	-	-	891	9 June 8.00 pm - 10 June 03.00 am
Dunaújváros	-	-	-	740±30	750±25	750±25	750±20	750±10	742-745	-	-	755	11 June 01.00 am
Dunaföldvár	-	-	-	-	710±25	710±25	710±20	720±10	710±5	721	-	721	11 June 04.00 - 11.00 am
Paks	-	-	-	-	880±30	880±25	880±20	890±15	885±10	895-900	-	891	11 June 07.00 am - 04.00 pm
Dombori	-	-	-	-	-	900±30	900±20	915±15	910±10	920±5	-	916	1 June 6.00 pm - 12 June 03.00 am
Baja	-	-	-	-	-	970±30	970±25	990±20	985±15	995±10	-	989	12 June 05.00 am
Mohács	-	-	-	-	-	-	950±25	965±20	955±15	965±10	958-963		

Table 3. Root-mean-square error of the peak water level forecasts issued by the Hungarian Hydrological Forecasting Service

Lead time (hours)							
192-216	168-192	144-168	96-120	72-96	48-72	24-48	0-24
860±30	The forecast (mean of the confidence interval) exceeds the Highest Water Level (HWL) at first time.						
830±30	The max of the confidence interval of the forecast exceeds the Highest Water Level (HWL) at first time.						

As seen in Table 3, the root-mean-square error of the Hungarian Hydrological Forecasting Service for example for the day before the peak was 4.96 cm compared to 7.26 cm 3 days before the peak.

The forecasts issued at different times can be tracked easily using the example of a Budapest gauge seen in *Figure 1*. For the sake of clarity, the figure shows only the forecasts issued prior to the peak.

The Hungarian Hydrological Forecasting Service tracked the evolution of the June flood wave of the Danube all the way down to the border cross section below Mohács and took into account the possible backwater effect of the Drava.

HHFS forecast also the expected peak level and its date for the border cross section.

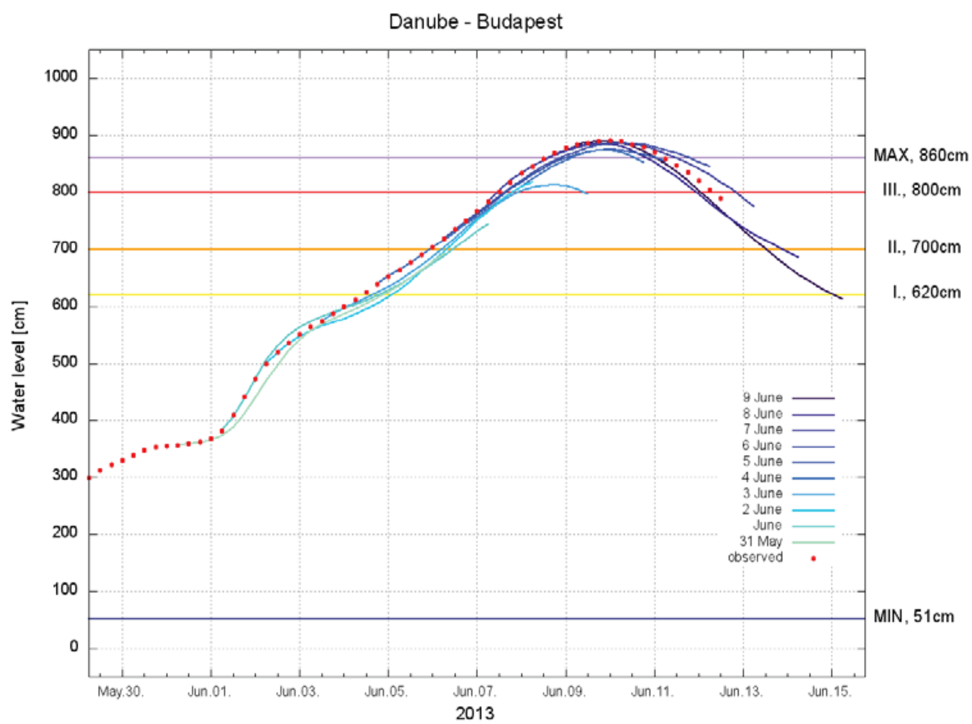

Figure 1. 1–6-day water level forecasts issued by the Hungarian Hydrological Forecasting Service for the Budapest section of the Danube on 1–9 June 2013

HHFS published special recession calculations and recession tables updated at least daily to help track the recession speed after the peak of the flood wave. During this period of recession, another short-term flood wave was registered, although it was far from the one breaking previous HHW records at many gauges. The magnitude of this new flood wave is characterised well by the fact that after the medium water level of the riverbed during the recession, the water increased to high levels, although it nowhere exceeded 70% in Hungary. The Hungarian Hydrological Forecasting Service continuously tracked the possible development and recession of this new flood wave and issued sufficiently accurate forecasts for the water regime daily or even more frequently as needed.

During the flood period, water levels at all major gauges except for Mohács were registered above HHW. The HHW value was exceeded by most at the Komárom gauge station where the 2013 water level was 43 cm higher than the one registered in 2002 at 802 cm (Katona et al., 2013). Peaking at 891 cm, the water level in Budapest was 31 cm higher in 2013 than the HHW value (Figure 1).

The lasting high water level on the Drava river in June 1965 produced a discharge close to 1,000 m^3/s higher than in June 2013. This is how the backwater effect of the Drava resulted in the HHW of the Danube at Mohács in 1965, which record remained unchallenged in 2013 due to the low water level of the Drava at the time (Figure 2).

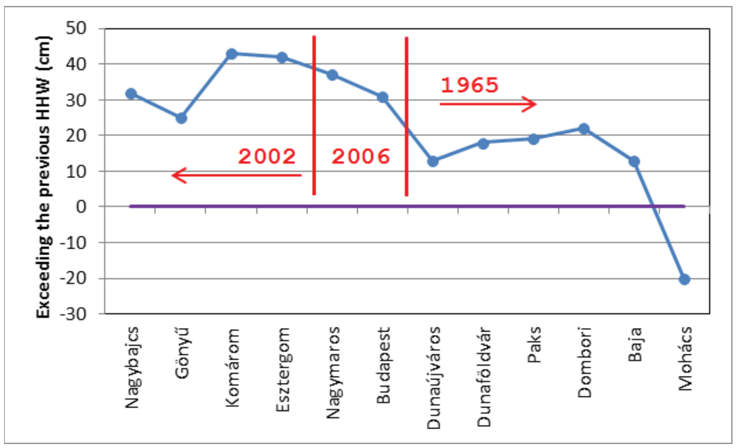

Figure 2. Difference between the June flood wave peak values and earlier HHW values (date of earlier HHW coloured by red)

4. Summary

The evidence collected on the circumstances of the development and propagation of the Danube flood wave of June 2013 as well as the forecasting activity of the Hungarian Hydrological Forecasting Service can be summarised as follows:

1. The 2013 flood wave resembled the flood of 2002 (Bálint, 2002) the most closely. The circumstances of its development once again raise the red flag that a significant, or even catastrophic, flood wave can develop on the Danube even in periods when the role that snow melting plays can be neglected.
2. The flood wave broke the HHW records all along the river's Hungarian section except for Mohács even tough a number of factors had a favourable effect on the water levels. Without a detailed analysis of the spatial distribution of precipitation, the most significant of those factors was that no significant flood waves were registered on any of the major left-bank tributaries of the Danube such as the Morava or the Vah. Even without

separate simulation tests, a comparison between with the 2002 and 2006 floods (Szlávik, 2006) clearly shows that in 2013 a flood wave on the Vah river would have increased the Danube's water level from Komárom downriver by a few decimetres and would have caused a situation that would have been hard to manage, especially along the section down to Budapest. The lasting high water level on the Drava river in June 1965 produced a discharge close to 1,000 m^3/s higher than in June 2013. This is how the backwater effect of the Drava resulted in the HHW of the Danube at Mohács in 1965, which record remained unchallenged in 2013 due to the low water level of the Drava at the time.

3. The upper catchment region of the Inn and the Salzach and the river Enns played a role less significant than usual in the development of the flood wave while the central and lower areas of the Inn–Salzach water system (including the Saalach, one of the tributaries of the Salzach producing excessive amounts of water) played a more important role than they normally do. The flood wave was further increased by the huge amounts of water that broke the records along the upper section of the Danube, which resulted in less steep increasing period, lower flattening and relatively slow decreasing period.
4. The significant lead time resulting from the use of the OLSER system of the Hungarian Hydrological Forecasting Service is of key importance in making timely preparations for flood defence.
5. Due to continuous improvements to the quantitative meteorological forecast models (primarily the generally used ECMWF model) and the OLSER system over the past years, we have by now reached a point where the previously separately managed flood peak forecasting and continuous forecasting can no longer be interpreted independently. Continuous forecasting taking into account precipitation forecasts and monitoring spatial changes of the complex physics-based concentration process also offers a level of accuracy suitable to identify peak values.
6. The forecasts operating with increased lead times due to the factors above would be inevitably burdened with even more uncertainty if lead times are increased any further. Thus, one of the key tasks for the future is to have forecast specialists, flood defence coordinators and other professional users review together the options for utilising the forecasts, the decisions that can be based on them and the correct interpretations of uncertainties.
7. During the flood defence and recovery operations between late May and 19 July 2013, the Hungarian Hydrological Forecasting Service forecast water regime for the Danube down to the Drava estuary, which information was provided to participants of the flood defence operation, their coordinators and the general public via regular updates on the HHFS website at

www.hydroinfo.hu, its phone and email hotlines, including the Hydrological Reports and the professional content of OMIT press releases, on a 24/7 basis, if needed.

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