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MODELLING OF EXTREME HYDROLOGICAL EVENTS ON A TISZA RIVER BASIN PILOT AREA, HUNGARY

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Abstract

Climate change takes more and more challenges to the water management. Future predictions show that the possibility of extreme floods and drought events are increasing, thus an additional task of the water management can be the fulfilment of the increasing water demands. These new extreme hydrological situations need to be properly handled in water management. The paper presents the first modelling results of the JOINTISZA project carried out on a selected sub-basin of the Tisza River, which is endangered by hydrological extremes. Our aim was to demonstrate the applicability of a one-dimensional hydrodynamic model to study the effects of the climate change. Future hydrological trends were introduced in the river basin and it was assessed how the results of climate models can be used for further hydrodynamic modelling. To address challenges of climate change and supply the stakeholders with an adequate amount of water, proper operation of the reservoir and the irrigation canals are needed. The use of hydrological modelling can be helpful to adequately distribute water resources.

Keywords: water quantity, drought, flood, hydrodynamic modelling, water demand, climate scenarios

INTRODUCTION

The Tisza River Basin (TRB) can be considered unique in several aspects among the river basins of Europe. In certain hydrometeorological situations, the chance of extraordinary floods is high. This was especially true at the beginning of the 2000s, when the flood waves set new record high water levels along the Hungarian section of the Tisza River (Szlávik, 2005). Over the last decades, drought has also taken more and more challenges to the experts of the local Water Directorates. The occasional extreme low water flow of the river is a problem especially in the flat areas of the Tisza River Basin. The climate change plays a major role in the emergence of these hydrometeorological situations (Lehner et al., 2006).

Regarding spatial and temporal distribution of drought in Europe, the major European droughts also impacted Hungary. Hungary has a high risk of developing a drought period, especially typical in the Great Hungarian Plain region (Tamás, 2016). The drought phenomenon can significantly increase because of the antropogenic activity and ineffective water management. It is expected that the extremely long, dry weather conditions will occur more regularly for years in Hungary (Szalai, 2009). The prevalence of the droughts has increased over the past decades, and especially the rolling drought phenomena have become critical when consecutive years of drought multiply the adverse effects of previous years (Pálfai, 1992). Regarding to the final report of the Danube River Basin Climate Adaptation Study from Mauser et al. (2018) the possibility of more intense and more harmful droughts are expected in the Middle Tisza region.The water demand is also expected to increase in the Great Hungarian Plain which causes new challenges in water management (Somlyódy, 2011). The local Water Directorate is responsible to provide adequate amount of water (NWS, 2017) to satisfy the water needs. This requires river basin planning, and proper water management.

In the JOINTISZA project a pilot area was selected in the Middle Tisza which is endangered by both extreme situations, such as floods and droughts. Our main goal was to investigate the impacts of climate change induced drought and flood issues on a smaller region within the TRB. This paper introduces the first modelling results which are the possible impacts of a long-lasting period with water scarcity in this pilot area.

We applied the forecasts of climate models produced by the Joint Research Centre. The data sets they generated – according to the predicted hydrological, meteorological, economic, and social conditions – were used in modelling as a boundary condition (Bisselink et al., 2018). With the help of these time-series, we aimed to explore possible medium and long-term conflict situations in water resources and to make recommendations for possible measures, thereby helping the water management planning of river basins with similar problems.

PILOT AREA

Characteristics of the pilot area

The selected pilot area is located in the flat region of the TRB in the middle of the Hungarian Great Plain (Fig. 1). The pilot area gets water from the Lake Tisza, which water intake is controlled by the local Water Directorate. This pilot area is selected because only a proper water management work could satisfy the water demands.

The size of the pilot area is 2884.6 km^2. It is bordered by the Tisza River from the west, and by the Lake Tisza from the north. The eastern border is the Hortobágy-Berettyó River and the Tiszafüredi main irrigation canal, and the southern border of the area is the Hármas-Körös River. The area is characterized by a very low elevation (79-100 mBf).

In the Tisza sub-basin the lofty sedimentary rocks dominates in the top 10 m caprock formations. Most of the soils are typically well-productive, so a significant part of the pilot area is suitable for agricultural activity. The typical genetic soil type in the region is the Chernozem. Large areas are covered with meadow and alluvial soils, which are common in the floodplains. The proportion of alkaline soils is exceptionally high in the Hortobágy-Berettyó region.

The size of the agricultural land is the largest in Hungary in the Tisza sub-basin, but from agro-ecological point of view this land use is considered to be the most unfavourable structure. Large area is arable land and they have low proportion of intensive cultures (vegetables, fruits). A significant part of the agricultural area consists of arable land (73 %), while the share of the garden, fruit and grapes represent less than 0.5%. The peculiarities of this river basin are the relative importance of fish ponds. The proportion of forest areas does not reach 5%.

Hungary's water network is basically determined by the fact that the country is located in the middle of the Carpathian Basin. In the country, about three-quarter of the water resources is transported by the Danube and the Drava Rivers, while almost only a quarter of the available water resources is transported by the Tisza River.

The Tisza is the second most significant river in Hungary. The Tisza’s full gradient is 30 m (5 cm/km) in Hungary. The minimum measured water flow was 56 m^3/s, and the maximum measured value was 2950 m^3/s at Kisköre. The average flow value is 507 m^3/s at this Tisza river section.

The Lake Tisza is the biggest artificial surface water in Hungary. The lake was artificially created when the Kisköre Barrage was constructed. The lake is operated as a reservoir, so it has two different operating water levels for summer and winter seasons. The summer water level usually lasts from the middle of March to the end of October, and it is 88.57±0.05 m. The surface of the Lake Tisza is 127 km^2, with a volume of 253 million cubic meters; more than 130 million m^3 can be utilized. Lake Tisza can be considered as a multi-purpose water management facility; its main utilizations are: water supply, hydropower (at the Kisköre Barrage), fishing and nature.

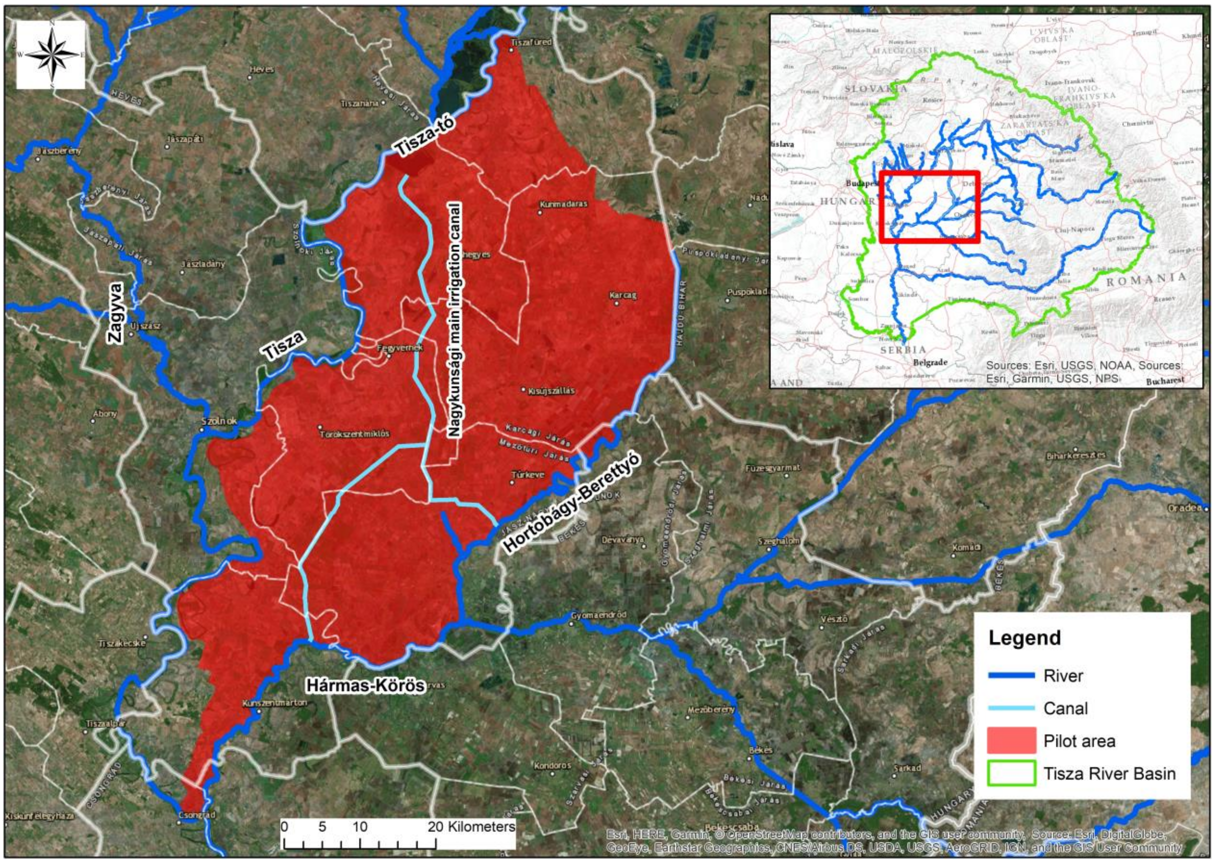

Fig. 1 Location of the selected pilot area located in the Tisza River Basin, Hungary

The area has a dry continental climate, and it has the driest climate in Hungary. The annual average temperature is between 10-11°C, and the monthly average temperature in July is around 21°C. The mean annual temperature fluctuation is 23.0-24.5°C. The annual amount of sunshine hours in the Hungarian Great Plain is over 2000 hours. Based on the measured data of the Middle Tisza District Water Directorate, the annual precipitation is about 520 mm in this area, which is the lowest annual average precipitation in the country. The territorial and temporal distribution of the precipitation is also extreme. The annual rainfall also varies within wide limits. Some years (e.g. the year of 2010 when the annual precipitation was 820 mm) had a lot of precipitation and it caused floods and inland excess waters. In the last some decades that even in the same year after a wet period a dry and warm period occurred with heavy drought.

Climate change can play a major role in the emergence of extreme conditions. Future predictions suggest that even more extreme drought periods may also occur more and more often (Mauser et al., 2018). Because of these extreme situations a well performed and appropriate water resource management planning and regulations are important. The pilot study intended to contribute to a better planning process that takes into account the climate change induced impacts on surface water quantity.

The pilot area has some particular characters that were taken into account when it was selected. The required amount of water by the stakeholders in the pilot area can be ensured only by the proper water management of the District Water Directorate (NWS, 2017). The water demand is satisfied by a dense canal network of the area from the Tisza River. In a dry period, the Lake Tisza can provide sufficient water for the region, but the water flow is exclusively managed by District Water Directorate into the pilot area. The special features described above have determined which model type could fit most to assist the water quantity management.

Nagykunsági irrigation system

The most significant irrigation system of the pilot area is the Nagykunsági irrigation system. Based on the water usage data of the Middle Tisza District Water Directorate, the annual volume of water supply of the area is around 15-20 million m^3 on average, but can reach 25 million m^3 in a drier period. The main irrigation canal in the irrigation system is the Nagykunság main canal. This canal gets water from the Lake Tisza through a water intake structure controlled by the local Water Directorate and passes the water to the Hármas-Körös and the Hortobágy-Berettyó Rivers. The water inflow is around 20-35 m^3/s in irrigation season (from April to September). The canal is split into two branches near Örményes. The overall length of the main canal is 74.5 km (including the western branch). The eastern branch of the canal is 18.07 km long. The Nagykunsági main irrigation canal flow out from the 403.000 fluvial km section of the Tisza and reaches the Hármas-Körös River at the 35.600 fluvial km section. The Eastern branch of the Nagykunsági main irrigation canal flow out from the Nagykunsági main canal, reaches the Hortobágy-Berettyó River at the 16.630 fluvial km section.

The water from the Nagykunsági main irrigation canal is distributed to various irrigation sections to reach the user (Fig. 2). The most important irrigation sections of the Nagykunsági irrigation system are the following: NK III, NK IV, NK V-1, NK V-2, NK VII-1, NK X, NK XII. Figure 2 shows the main parts of these irrigation sections; the water can be drained to the other part of the pilot area. The irrigation canals have several hydraulic structures to properly drain the water through the Nagykunsági irrigation system. The Nagykunsági main irrigation canal has 7 inline structure (Fig. 2). The main aim of these structures to ensure water retention, and to provide proper water distribution.

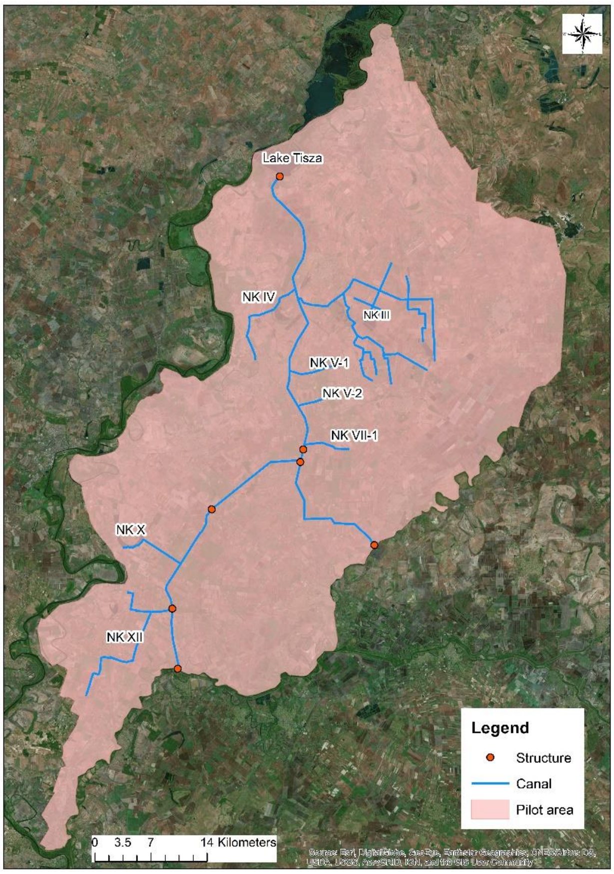

Fig. 2 Irrigation sections of the Nagykunsági irrigation system

METHODS

One dimensional hydrodynamic model

HEC-RAS is capable of performing one-dimensional water surface profile calculations for steady varied flow in natural or constructed channels. It is the basic equation and numerical model of free-surface, one-dimensional, continuously variable non-permanent water movement. The most important conditions are: one dimensionality, graduality, free-surface, and non-permanent character. Of these, the first two are the hardest to follow; these are the most important constraints. In our case, when we model a non-permanent hydraulic phenomenon in a complex cross-section of a meandering watercourse network, the validity of these conditions has a decisive influence on usability (US Army Corps of Engineers, 2016).

In its current structure, the database of the model includes the 600 km long river section between Tiszabecs and Szeged from the Tisza. The model also contains the canals of the pilot area. The total length of streams involved into calculations exceeds 2 000 km. We installed 102 bridges and 19 inline structures into the model. The model contains the Nagykunsági irrigation canal, which is the most important irrigation canal of the pilot area.

The complete hydrodynamic model includes the following river sections (Fig. 3):

- Tisza, from Tiszabecs to Szeged (600 km),
- Szamos, from Csenger to outfall (50 km),
- Kraszna, from Ágerdőmajor to outfall (45 km),
- Bodrog, from Felsőberecki to outfall (50 km),
- Hernád, from Gesztely to outfall (23 km),
- Sajó, from Felsőzsolca to outfall (50 km),
- Zagyva, from Jásztelek to outfall (55 km),
- Berettyó, from Pocsaj to outfall (68 km),
- Sebes-Körös, from Körösszakál to Köröstladány (54 km),
- Fehér-Körös, from Gyula to outfall (9 km),
- Fekete-Körös, from Ant to Remete (16 km),
- Hármas-Körös, from Gyoma to outfall (90 km),
- Hortobágy-Berettyó, from Ágota to outfall (80 km),
- Nagykunsági irrigation canal (with the eastern and western branches), from Abádszalók to Mezőtúr/Öcsöd (110 km).

We have advanced the stream system of the model by more than 2 000 cross sections. The cross sections are the basis of the one-dimensional models. The calibration and the roughness coefficient are only party compensate the possible inaccuracies of the cross-sections. The model stability is greatly improving if the cross sections are as dense as possible. Based on previous modelling experiences, the optimal distance between cross sections - from model point of view - is 400 - 800 m for the Tisza, and 200 - 400 m for the tributaries of the Tisza. For the irrigation canals, the optimal distance is 200 - 400 m.

The hydrodynamic model has 14 upstream, and 1 downstream boundary condition. The boundary conditions of the rivers are located on the Hungarian border sections. We have chosen these points to minimize the impact of the boundary conditions on modelling results in the pilot area. At each point there are flow data available for input data.

The applied HEC-RAS model gives detailed description of the entire river system and provides an opportunity for taking into consideration the hydraulic engineering structures, as well as bridges, barrages, culverts, overflow weirs, floodgates, bottom stages, bottom sills, side overflows and gates, static reservoirs, pump head stations and water intakes (US Army Corps of Engineers, 2016). The model includes 102 bridges, and 16 inland structures, and it also contains water intakes. We took into the model every irrigation section of the Nagykunsági irrigation system as a point like water intakes. The model also contains every directly water use along the Nagykunsági main irrigation canal, so water consumption can be tested as a simple drainage. We used

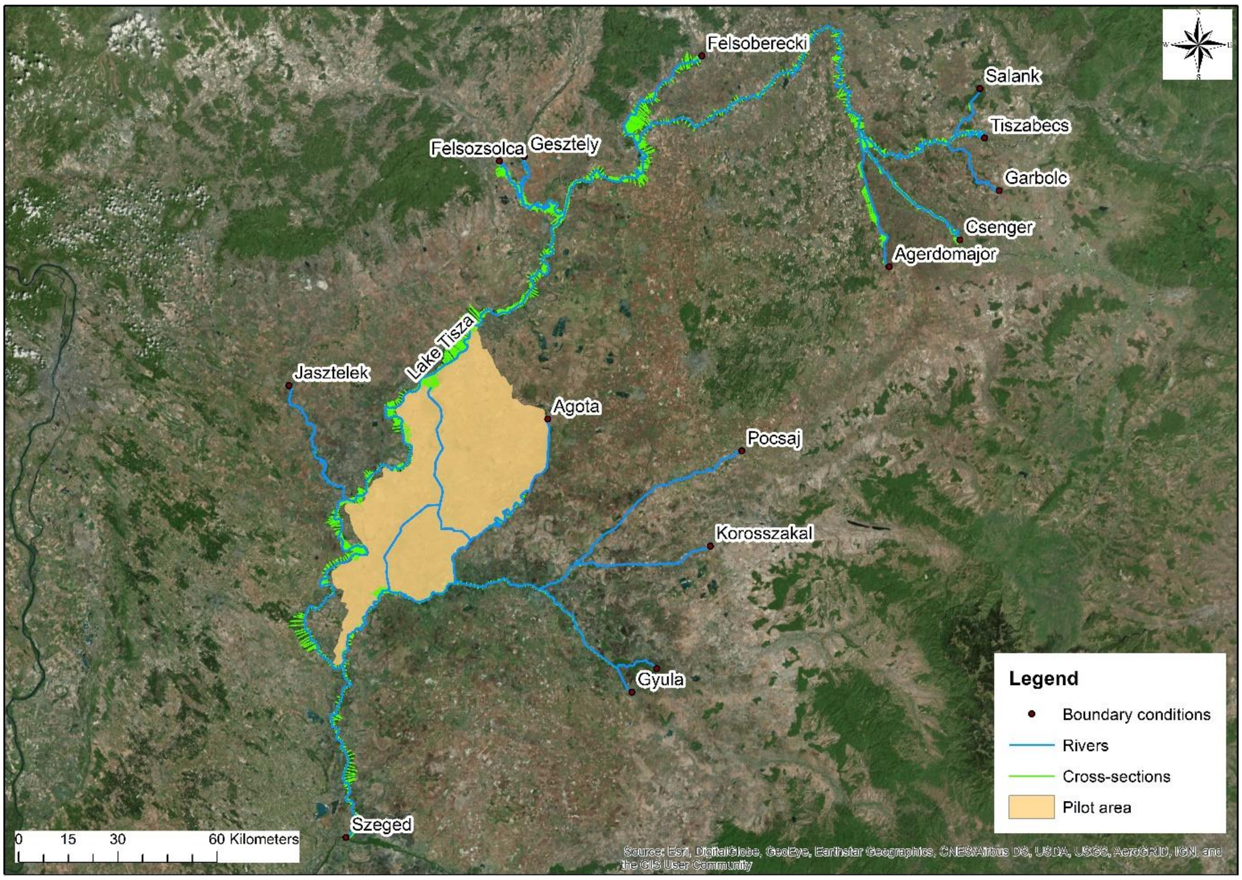

Fig. 3 The layout and the boundary conditions of the model

the possible water demand values for input data which are based on the survey of the Hungarian Chamber of Agriculture (NWS, 2017).

For calculation of the water discharge capacity of the main river bed of Tisza as well as for taking the flood plain vegetation into consideration we used the roughness (smoothness) factors given in the Table 1 in the course of calibration of the model. We determined the vegetation on the flood plain by aerial photographs, i.e. by ortho-photographs, as well as by the results of on-site inspections. The roughness factor was changed crosswise according to flood plain vegetation. The roughness (smoothness) factor assigned to these was determined on the base of the prescriptions of the Hungarian standard, as well as on the base of values applied also by HEC-RAS and proposed by Chow (1959).

Table 1 Roughness / smoothness coefficients

No.	Type	n ($s/m^{1/3}$)		k ($m^{1/3}/s$)	
		Min	Max	Min	Max
0	River/canal channel	0.060	0.017	16.67	58.8
1	Pasture	0.050	0.025	20.00	40.0
2	Plough-land	0.050	0.020	20.00	50.0
3	Sparse shrub	0.080	0.035	12.5	28.6
4	Dense shrub	0.160	0.040	6.25	25.0
5	Forest without undergrowth	0.120	0.030	8.33	33.3
6	Forest with undergrowth	0.200	0.080	5.00	12.5

The calibration of the model was accomplished gradually, starting with the shorter sections. We assembled together the individual section and then performed the river sections.

The calibration of Tisza and its tributaries was made for the low-water period of the year 2012. On the river section between Tiszabecs and Szeged, the difference between the calculated water level and the observed was between 0 and 10 cm in absolute values, which can be considered as a very good result. The pilot area's canal network calibrated separately. We used data from the year of 2013 to calibrate the irrigation canals. The difference between the calculated water level, and that of observed was between 0 and 10 cm, like the river network. After the calibration was made, the separate water streams were connected.

Climate scenarios of the Joint Research Centre

The Joint Research Centre (JRC) studied the effects of changing climate, land use, and water demand on water resources in the Danube River Basin using climate induced runoff modelling technique (Bisselink et al., 2018). The water resources calculations were done with the LISFLOOD 2.0 model which is a GIS-based spatially-distributed hydrological rainfall-runoff-routing model (De Roo et al., 2000, Van der Knijff et al., 2010; Burek et al., 2013). As a result of the runoff modelling, water flow data were made available for our work for the rivers of the Tisza River Basin.

In the JRC analysis, 11 different European EURO-CORDEX climate scenarios have been used (Table 2). The Coordinated Downscaling Experiment over Europe (EURO-CORDEX, Jacob et al. 2014) is an international climate downscaling initiative that aims to provide high-resolution climate projections up to 2100 (Bisselink et al., 2018).

Flow time-series were made available for our work for every boundary condition calculated from the JRC runoff model. Time-series were from 2011 to 2099 for each 11 climate projections. In addition to the boundary

Table 2 EURO-CORDEX climate projections (Bisselink et al., 2018)

No.	Climate scenario	Institute	Global climate model	Reg. climate model	Exceeding 2°C warming
1	CLMcom-CCLM4-8-17_BC_CNRM-CERFACS-CNRM-CM5_rcp85	CLMcom	CNRM-CM5	CCLM4-8-17	2044
2	CLMcom-CCLM4-8-17_BC_ICHEC-EC-EARTH_rcp85	CLMcom	EC-EARTH	CCLM4-8-17	2041
3	CLMcom-CCLM4-8-17_BC_MPI-M-MPI-ESM-LR_rcp85	CLMcom	MPI-ESM-LR	CCLM4-8-17	2044
4	DMI-HIRHAM5-ICHEC-EC-EARTH_BC_rcp85	DMI	EC-EARTH	HIRHAM5	2043
5	IPSL-INERIS-WRF331F_BC_rcp85	IPSL	IPSL-CM5A-MR	INERIS-WRF331F	2035
6	KNMI-RACMO22E-ICHEC-EC-EARTH_BC_rcp85	KNMI	EC-EARTH	RACMO22E	2042
7	SMHI-RCA4_BC_CNRM-CERFACS-CNRM-CM5_rcp85	SMHI	CNRM-CM5	RCA4	2035
8	SMHI-RCA4_BC_ICHEC-EC-EARTH_rcp85	SMHI	EC-EARTH	RCA4	2041
9	SMHI-RCA4_BC_IPSL-IPSL-CM5A-MR_rcp85	SMHI	IPSL-CM5A-MR	RCA4	2044
10	SMHI-RCA4_BC_MOHC-HadGEM2-ES_rcp85	SMHI	HadGEM2-ES	RCA4	2030
11	SMHI-RCA4_BC_MPI-M-MPI-ESM-LR_rcp85	SMHI	MPI-ESM-LR	RCA4	2044

conditions, discharge data were also available for an internal river section of the Tisza, which was the inflow section of the river into Lake Tisza. This point was an important control point in the Middle Tisza from water management point of view. Using the data of this control section it was possible to examine how much water flows into the Lake Tisza from the Tisza River. If the flow of this river section decreases below 105 m^3/s water shortage can be considered, and when discharge falls below 60 m^3/s, water restrictions may be needed (MTDWD, 2013).

RESULTS

Hydrological changes of the Middle Tisza

Analysis has been made for the 11 flow time-series which refers to the inflow section of Lake Tisza, which can be used to quantify future trends in the Middle Tisza hydrology.

In the months of September and October will have the highest probability when the flow will decrease below 60 m^3/s at the river section near Tiszafüred. The return time for extreme low-water periods is 3-4 years in all 11 climate projections. Based on the data released by the JRC, the occurrence of more and more long-lasting low-water periods are also predicted for the second half of the century. The most extreme "SMHI-RCA4_BC_ICHEC-EC-EARTH_rcp85" run occurred a 128-day period below 60 m^3/s. with a 24.5 m^3/s minimum discharge.

In addition to the extreme low-water conditions, some climate scenarios have also generated extraordinary flood waves. In the case of two projections (CLMcom-CCLM4-8-17_BC_CNRM-CERFACS-CNRM-CM5_ rcp85, IPSL-INERIS-WRF331F_BC_rcp85), the maximum flow is above 4500 m^3/s, which would pose a serious flood risk to the Middle Tisza in the future, with special regard to the Kisköre barrage.

It is based on the analysis to define which climate scenario should be used as the boundary condition of the hydrodynamic model. According to the analysis, the "SMHI-RCA4_BC_ICHEC-EC-EARTH_rcp85" is selected to study low-water periods.

Water demand changes of the study area

It was necessary to determine the future water demand of the pilot area for the study of water resources. The Hungarian Chamber of Agriculture conducted a nationwide water demand survey (GWDM, 2018).

Based on the survey it can be stated that the water demand is well above the amount of water currently used in Hungary. The annual water demand of the pilot area exceeds 55 million m^3, which is expected to increase in the future. 80 % of this value refers to the Nagykunsági irrigation system. It can be stated, that the Nagykunsági irrigation system satisfies the large part of the water needs. Part of the water demand can be assured directly from the Nagykunsági main irrigation canal, and the other parts of water needs are distributed through the irrigation sections (Fig. 4). These water demands have become the part of the hydraulic model as water abstractions.

According to the survey, there are 6474 locations for water uses. 3914 are new request for using water from this number. These new demands account 23 million m^3 quantity of water in a year, almost half of the total annual water needs in the pilot area.

Results of the hydraulic modelling

The modelling scenario is a long-lasting low-water period, whereby the water flow to the area is lower than the sum of water flowing to the tail-water at Kisköre barrage and of into the irrigation canals from the Lake Tisza.

The boundary conditions are selected based on the statistical analysis of the water flow datasets produced by the JRC. In this scenario, there are several periods with water scarcity. The year of 2085 of the time series includes an extreme low-water period, which data sets of the year have been used as the boundary conditions of the model at every upstream river sections. At the river section of the Tisza near Tiszafüred, for more than 3 months, the flow of the river is below 105 m^3, which is a period with water scarcity.The boundary condition of the model for the Tisza is shown in Figure 5.

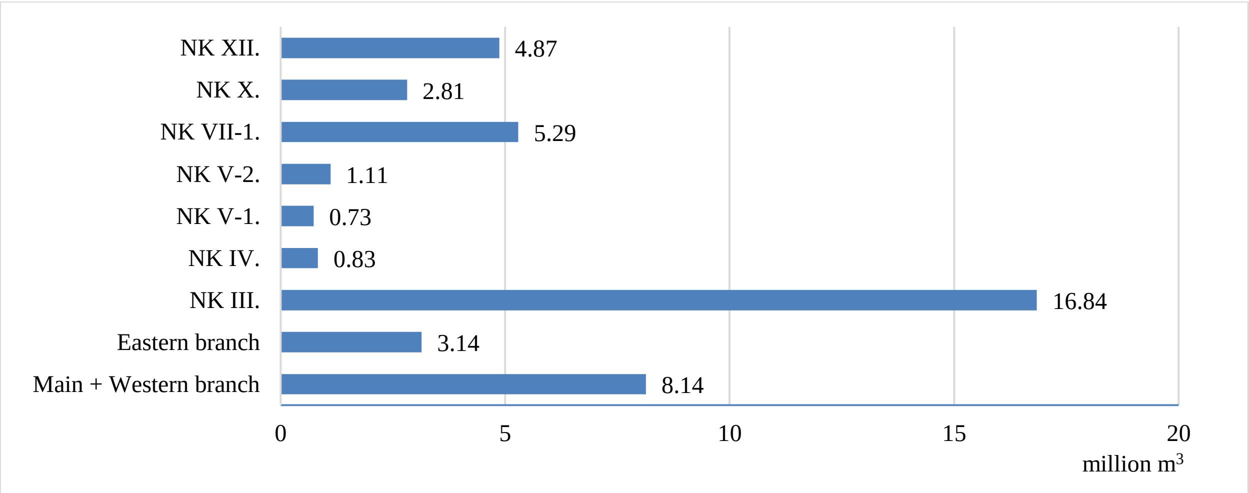

Fig.4 The distribution of future water demand in the Nagykunsági irrigation system

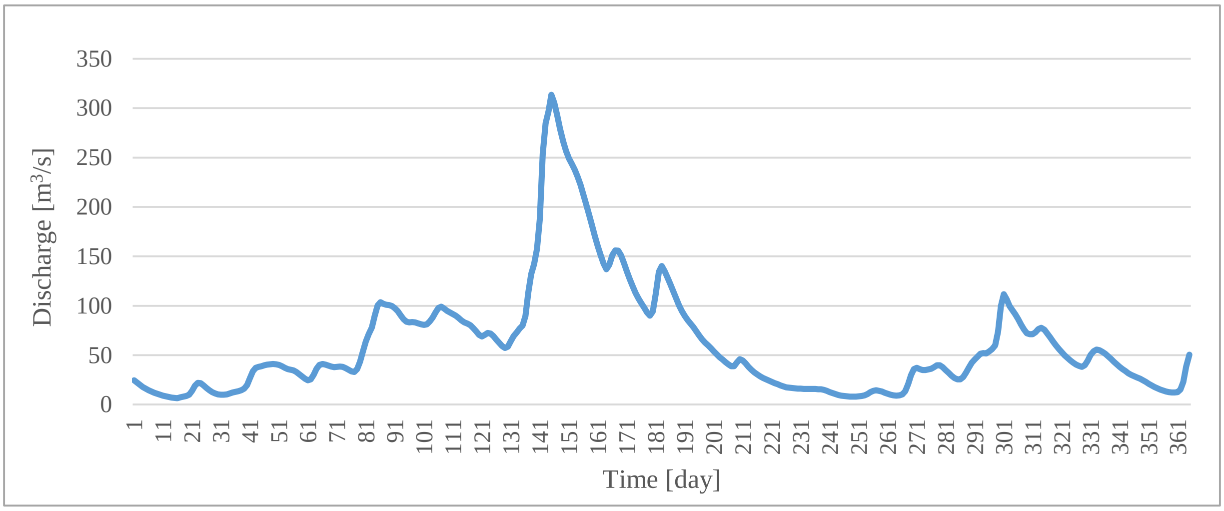

Fig. 5 Boundary condition of the hydrodynamic model for the Tisza River in the modelling scenario

In the modelling scenario - when the river's flow falls below 100 m^3/s - the water level of the Lake Tisza gradually began to decrease. The trend continues for two months when the discharge at the upper section of the river increase above 100 m^3/s. During the critical period, the amount of water which is drained from the Lake Tisza to the Nagykunsági main irrigation canal is continuously ensured and corresponding to the water demands (Fig. 6). We studied how quickly the stored water of Lake Tisza would be consumed.

Figure 7 shows the development of water flow and water level at Kisköre barrage in the modelled year. In the first half of the year there is enough water flow to the river to maintain the operating water level (88.67 ± 0.05 m) of the reservoir. Then in the summer months, the river flow gradually decreases until it reaches the critical 60 m^3/s value. This low water condition lasts for one and a half months when the water level of the reservoir is reduced by 2.96 m. This level of water is reducing in order to meet the water demands in the pilot area without any problems and to ensure the minimum 60 m^3/s to the Kisköre barrage tail-water. This minimum flow of water is needed in addition to the ecological goals, it is also necessary for the water supply of Szolnok.

In addition to provide sufficient quantity of water at the river section downstream of Kisköre, enough water is also drained into the irrigation canals. In the Middle Tisza there is a Water Restraint Plan which determines the cases when the amount of water taking from the Lake Tisza to the irrigation canals should be limited. According to the regulations 14.4 m^3/s flowrate must be secured from the eastern branch of Nagykunsági main irrigation canal to the Hortobágy-Berettyó, as well as 1,6 m^3/s from the western branch of Nagykunsági main irrigation canal to the Hármas-Körös (MTDWD, 2013). The main goal with these minimum flows is

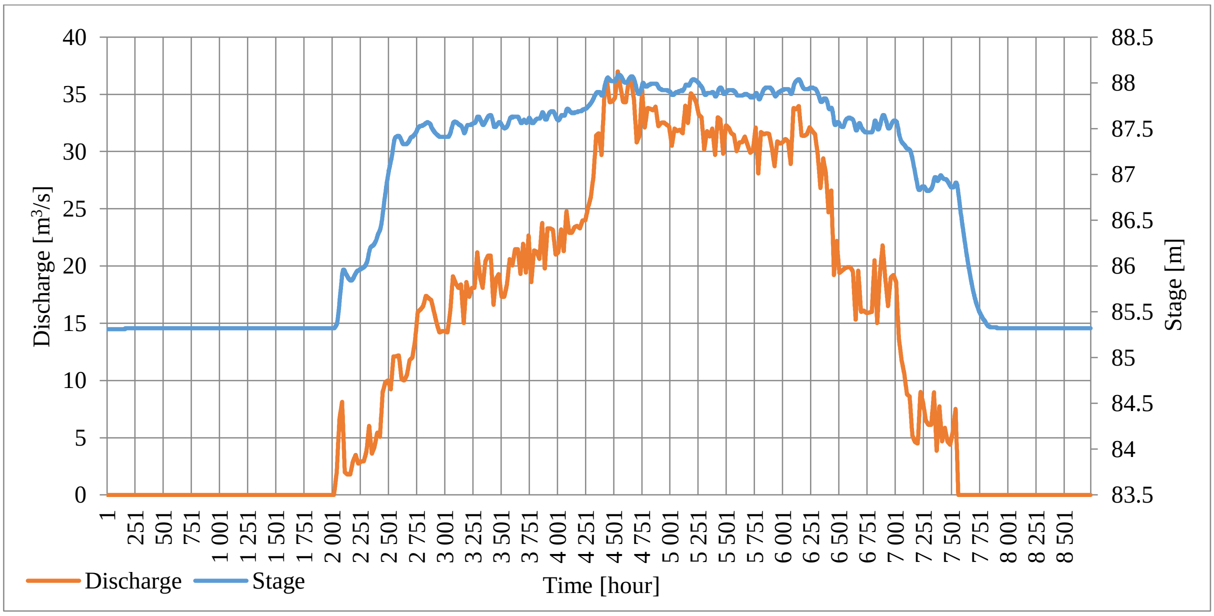

Fig. 6 Discharge and stage at the inlet point of the Nagykunsági main irrigation canal

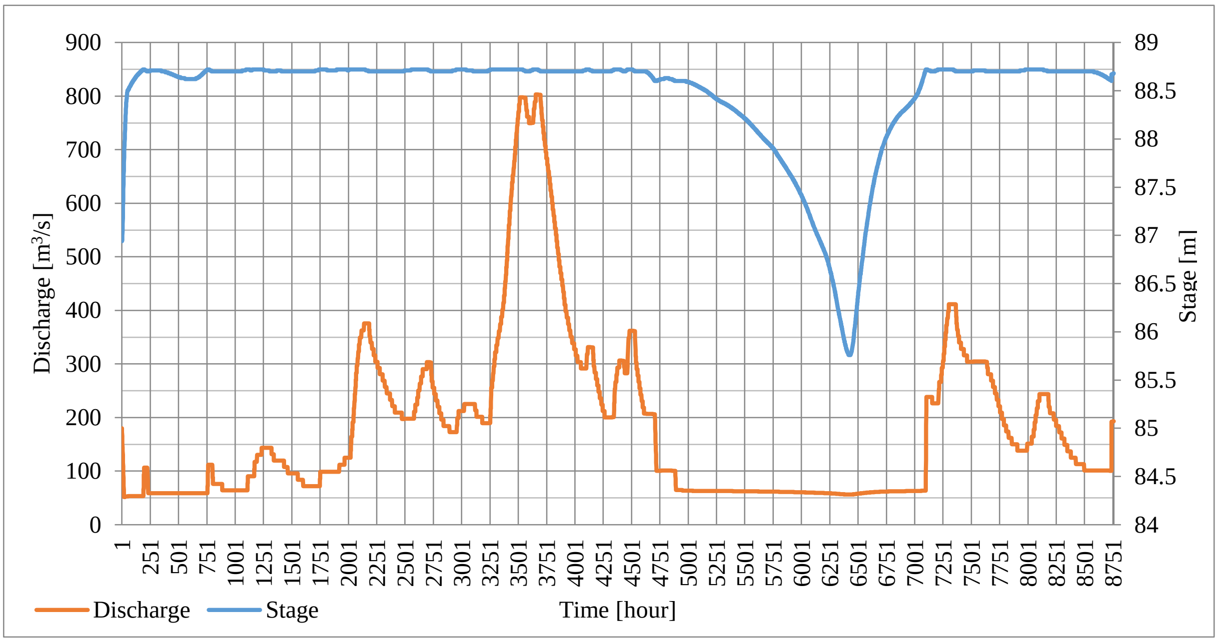

Fig. 7 Discharge and stage at the headwater of Kisköre barrage

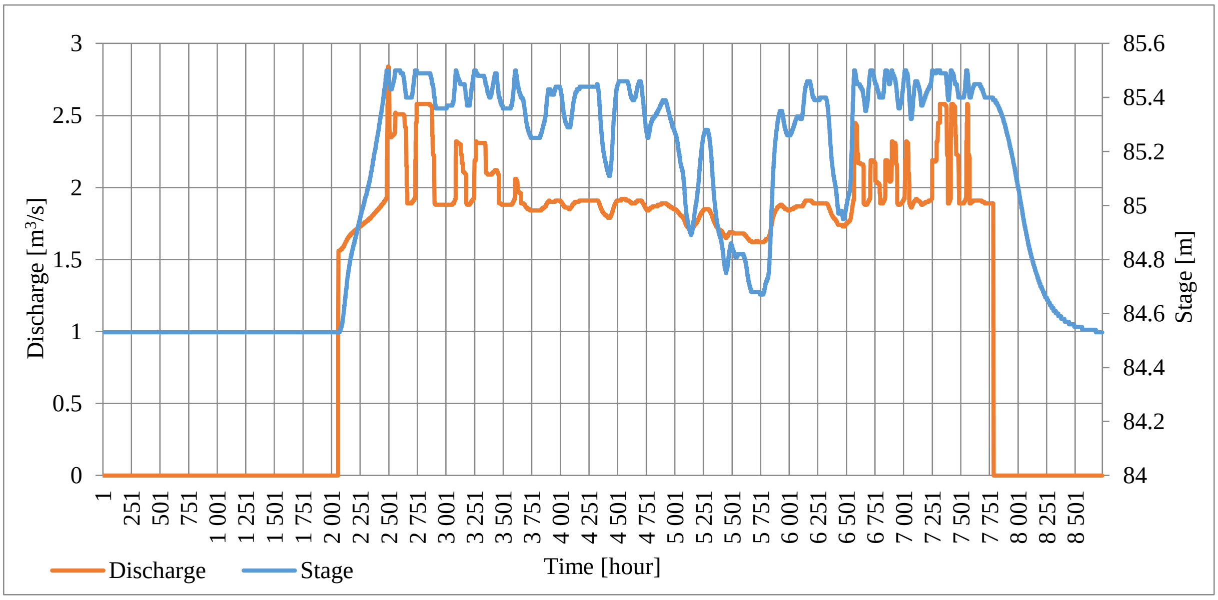

Fig. 8 Discharge and stage at the outflow section of the Nagykunsági main irrigation canal (with the western branch)

to provide water for the Körös Valley. However, when the discharge of the Tisza falls to a critical level (below 60 m^3/s), the amount of water passed through the Nagykunsági main irrigation canal may need to be reduced. In the first scenario of modelling, this regulation was not considered. In the model scenario the minimum flowrate was guaranteed at the outflow sections of the Nagykunsági main irrigation canal. Figure 8 shows the development of the water flow and stage at the outflow section of the western branch. 1.62 m^3/s is the minimum flow during the summer period, which is almost the same as the value in the operating rule.

Figure 9 shows the development of water flow and water level at outflow section of the Eastern branch of the Nagykunsági main irrigation canal in the modelled year. The time series shows that the water flow is between wide limits during the entire irrigation period. This is caused by the operation order of the inline structure at the outflow section. The gate is set to maintain a certain water level at the headwater, which is 84.55±0.05 m. The average discharge is 14.9 m^3/s during the irrigation period.

The results of the model show what is happening with the water resources of the Lake Tisza in an extreme low-water situation. The model runs show that the Lake Tisza is able to supply the area with water during a period with water scarcity, but in extreme cases the water level may become critically low. The water restrictions are not in the model scenario and it was assumed that the water level of Lake Tisza would not reach critically low level. These steps were not included in this model version because the main goal was to investigate at what condition the pilot area can be supplied with enough water.

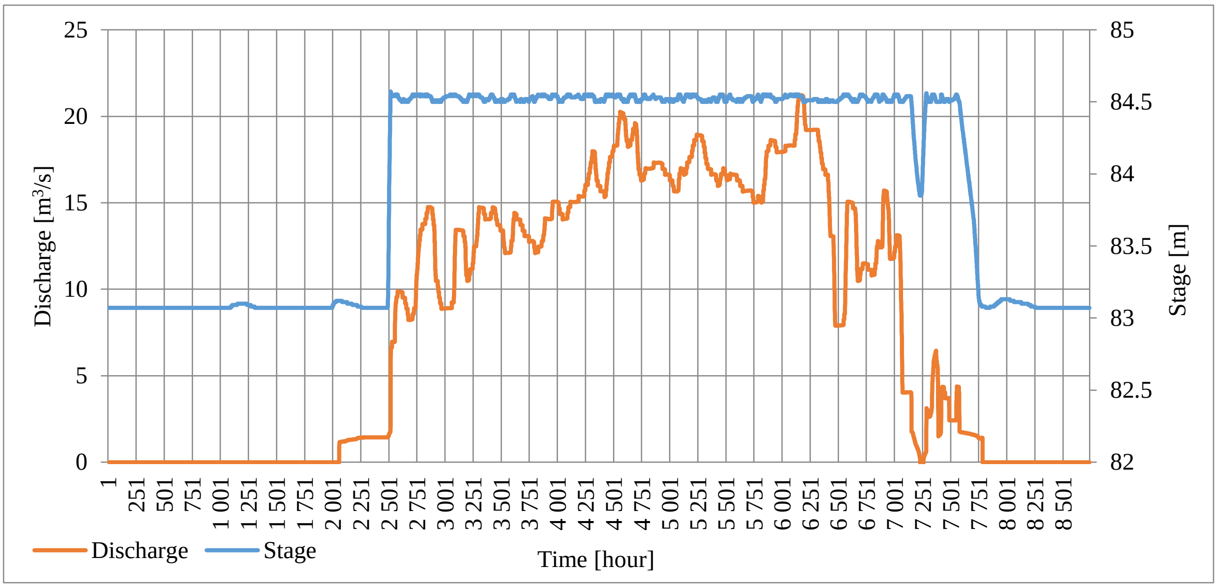

Fig. 9 Discharge and stage at the outflow section of the Nagykunsági main irrigation canal (with the eastern branch)

CONCLUSIONS

The climate change can have serious impact on the selected pilot area, which pose also challenges to the water management of the area. Lake Tisza has the highest value among water resources in the Middle Tisza region, which can provide great help in overcoming these challenges. Supplying the stakeholders with an adequate amount of water proper operation of the reservoir (Lake Tisza) and the irrigation canals are needed. It can be helpful to use hydrological modelling to distribute water resources in a proper way, which means that enough water has to be available.

As demonstrated in the modelling results, the necessary water could be provided in the pilot area without the introduction of water restriction measures. In case of long-lasting drought period the water users of the area could have enough water, but in exchange that the water resources of the Lake Tisza would be reduced to a dangerous low level. This could cause serious ecological, economic and social conflict.

Based on the experiences of this model results, the further researches could include water restriction measures. It will also help to assess how the water level of the Lake Tisza can be maintained within the regulation range, while at the same time limiting the use of water in the area according to the water restriction plans in consensus with the stakeholders.

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References

Bisselink, B., Bernhard, J., Gelati, E., Adamovic, M., Jacobs, C., Mentaschi, L., Lavalle, C. and De Roo, A., *Impact of a changing climate, land use, and water usage on water resources in the Danube river basin*, EUR 29228 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79- 85889-5, DOI:10.2760/89828, JRC111817

Burek, P., De Roo, A.P.J., van der Knijff, J.M, 2013. LISFLOOD – Distributed Water Balance and Flood Simulation Model – Revised User Manual. Joint Research Center, Institute for Environment and Sustainability, European Union.

Chow V.T. 1959. Open-channel hydraulics, McGraw-Hill Book Co, 680 p, New York

De Roo, A.P.J., Wesseling, C.G., Van Deursen, W.P.A. 2000. Physically-based river basin modelling within a GIS: The LISFLOOD model. *Hydrological Processes* 14, 1981–1992. DOI: 10.1002/1099-1085(20000815/30)14:11/12<1981::aid-hyp49>3.3.co;2-6

GDWM (General Directorate of Water Management), 2018. Database of the national water demand survey (Nemzeti öntözési igény felmérés adatbázisa). In Hungarian.

Jacob, D., Petersen, J., Eggert, B., Alias., Christensen, O.B., Bouwer, L.M., Braun, A. et al. 2014. EURO-CORDEX, *Reg Environ Change* 14, 563–578. DOI: 10.1007/s10113-013-0499-2

Lehner, B., Böll, P., Alcamo, J., Henrichs, T., Kaspar, F. 2006. Estimating the impact of global change on flood and drought risks in Europe: A continental, integrated analysis. *Climatic Change* 75, 273–299. DOI: 10.1007/s10584-006-6338-4

Mauser, W., Stolz, R., Weber, M., Ebner, M. 2018. Danube River Basin Climate Change Adaptation – Final Report, Germany.

MTDWD (Middle Tisza District Water Directorate) 2013. Water management strategy in the Middle Tisza. Online available at: http://kotivizig.vizugy.hu/doksik/vizkeszletgazdalkodasi_strategia.pdf (in Hungarian)

Middle Tisza District Water Directorate (MTDWD), 2018. Water restriction plan of the Middle Tisza District Water Directorate. In: KÖTIVIZIG (ed.) KÖTIVIZIG vízkorlátozási terve

NWS, 2017. National Hungarian Water Strategy. General Directorate of Water Management. Online available at: http://www.kormany.hu/download/6/55/01000/Nemzeti%20V%C3%ADzstrat%C3%A9gia.pdf (in Hungarian).

Pálfai, I. 1992. Aszályok a *Tisza*-völgyben. (Droughts in the Tisza valley). In: Fejér L., Kaján I., (ed.) Mérlegen a Tisza-szabályozás, MHT-OVF, Budapest, 33–40.

Somlyódy L. 2011. Magyarország vízgazdálkodása: helyzetkép és stratégiai feladatok (Water management of Hungary: situation and strategic tasks), MTA, Budapest. Online available at: http://old.mta.hu/data/Strategiai_konyvek/viz/viz_net.pdf (in Hungarian)

Szalai, S. 2009. Drought tendencies in Hungary and its impacts on the agricultural production. *Cereal Research Communications* 37, 501–504.

Tamás J. 2016. Kihívások az aszálykutatás területén. (Challenges in drought research). *Hidrológiai Közlöny* 96 (2), 13–20. (in Hungarian)

US Army Corps of Engineers, 2016. HEC-RAS River Analysis System – User's Manual, USA.

van der Knijff, J.M., Younis, J., De Roo, A.P.J. 2010. LISFLOOD: A GIS-based distributed model for river-basin scale water balance and flood simulation. *International Journal of Geographical Information Science* 24(2), 189–212. DOI: 10.1080/13658810802549154