REPORT ON TESTING DYNAMIC MODEL TO ASSESS CUMULATIVE EFFECT OF N(S)WRM (PILOT ACTION)

D. T2.4.1

Version 4

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WP	WP2 Effectiveness of the Natural Small Water Retention Measure
Activity	Act. 2.4 Application of dynamic water quantity and/or quality models (Pilot Action)
Activity leader	MTDWD
Number and name of the deliverable/output	D.T2.4.1 Reports from testing the dynamic model to assess cumulative effect of N(S)WRM (Pilot Action)
Participating partners	all
Type of the deliverable/output (analysis, report, guideline, workshop, brochure, etc.)	Analysis/report
Purpose of the deliverable/output	The report summarize experiences from testing of cumulative effects of planned measures with 1 D HEC-RAS modelling work.
Connection with other deliverables	All WPs
Start date	**2017**
End date	**November 2019**

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1. Application of the hydraulic model

1.1. Description of the river network

The pilot catchment that the Middle-Tisza District Water Drectorate (PP5) selected for testing dynamic tools is situated in the middle of the Hungarian Great Plain (Fig.1). The pilot area is surrounded by three rivers, namely the Tisza, the Hármas-Körös and the Hortobágy-Berettyó.

The most important tool for regional water supply is Nagykunsági irrigation system, the Nagykunsági Main canal and its East branch connects the Tisza River with the Hortobágy-Berettyó and the Hármas-Körös rivers, providing water for the two rivers. Furthermore, it also works as a dual-purpose canal that start at Abádszalók from Lake Tisza.

The Nagykunsági Main canal 41.684 km long, it branches out into East and Main (west) branches at Örményes. The East branch is 17.938 km long and it flows into Hortobágy-Berettyó at Túrkeve. The main branch is 34.915 km long and it flows into the Hármas-Körös River at Öcsöd.

The pilot area is well-drained by open canals as besides the extended irrigation network significant density of drainage and multipurpose canal networks are available in the area (i.e. Álomzugi, Mezőtúri VI., Harangzugi etc. canal systems). The channel networks of the pilot area have a very important role in agricultural water supply and mitigation of excess water.

The canal systems have a high-built character, thus a traditional rainfall-runoff hydrological model can't be applied for our pilot area because of very minor or almost zero direct runoff from the territory into the canals. Consequently it was concluded that the hydraulic model which can be used for such a special area is a hydrodynamic model type.

HEC-RAS modelling system was selected and applied for this pilot study.

Figure 1. The map of the Hungarian pilot area

1.2. Geometric data (DEM, cross-sections)

The geometry and cross-section data of the Nagykunsági canal come from our own measurement. Cross-sections were surveyed in 2013, with cross-section distance varying from 50 to 500 meters. In order to keep the hydraulic model numerically stable, cross-sections were linearly interpolated to a unified spatial step of 200 m and the measured and interpolated cross-sections were used to reproduce the 1D river geometry within the model (Fig. 2).

The source of the geometry and cross-section data of Álomzugi, Mezőtúri VI. and Harangzugi canals is from our register plan and BEKKA project measurement (2013-2015). (Fig. 3)

Geometry data of Hármas-Körös and Hortobágy-Berettyó come from our register plans, our measurement and atlas.

For roughness coefficient the Manning coefficient was used with initially uniform in space value for both canals ($n=0.03 m/s^{-1/3}$) and overbanks ($n=0.1\ m/s^{-1/3}$). Later on, these values were modified during calibration.

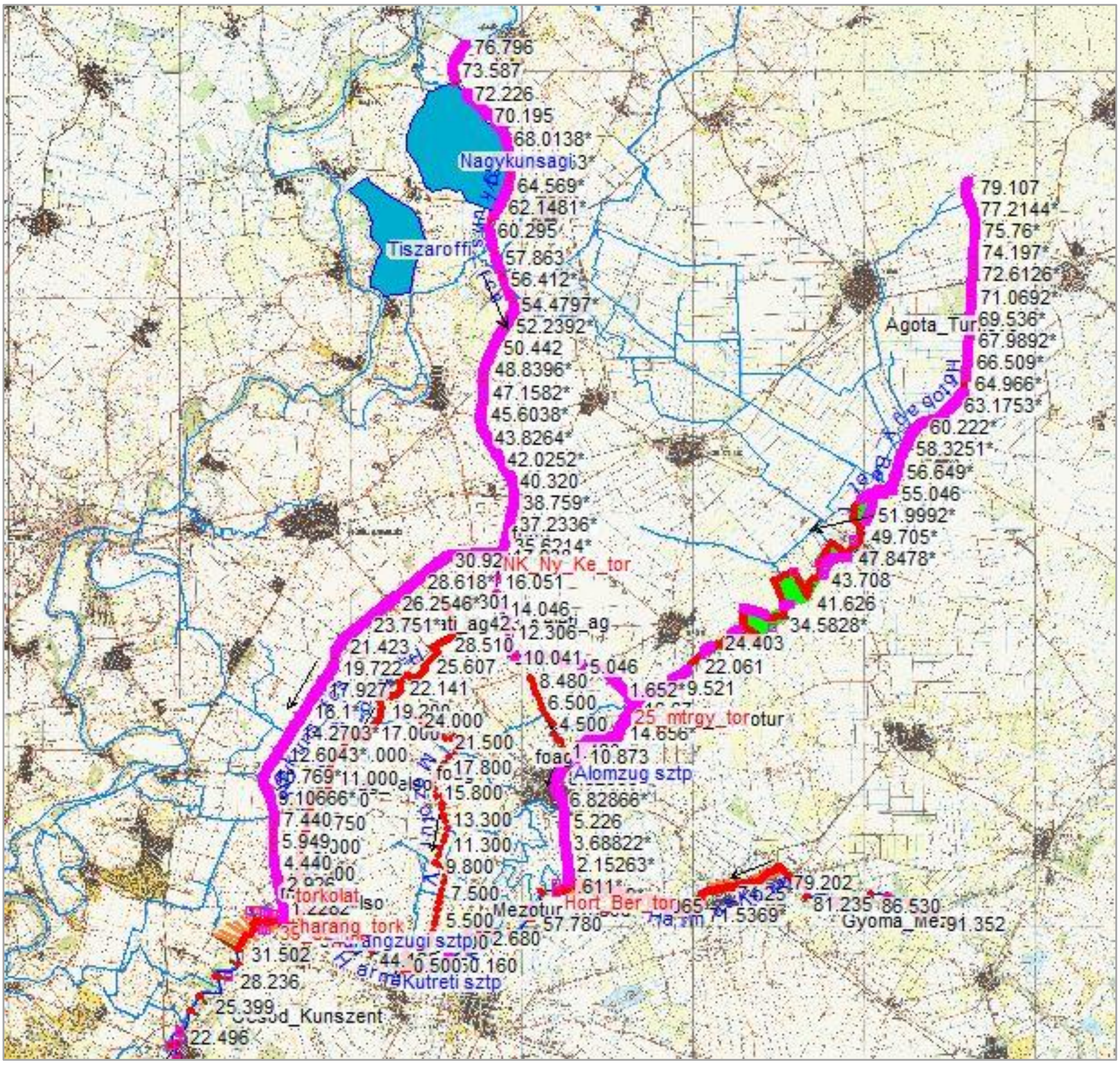

Figure 2. The river network used in the 1D model

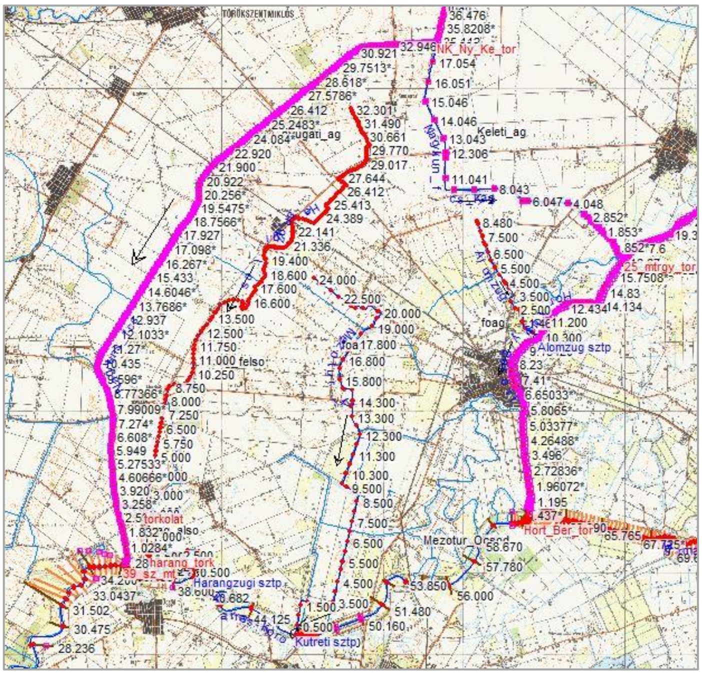

Figure 3. West and east branchs and Álomzugi, Mezőtúri VI., Harangzugi canals

1.3. Description of the model structure

The network (Fig. 2) of our model consists of 79.107 km Hortobágy-Berettyó, 91.352 km Hármas-Körös, the Nagykunsági Main canal and its east and west branches. In addition, three canals between west and east branches, namely the Harangzugi, Mezőtúri VI. and Álomzugi canals were also included into the model.

In the pilot area there are a lot of inline structures, water demands and pump stations. We built one inline structure into the model along the Nagykunsági Main canal, 3 structures along the west branch, and 2 ones along the east branch. Furthermore, one inline structure was considered along the Harangzugi, Mezőtúri and Álomzugi canals each (Tab. 1). In addition, water intakes and point sources were set up, but pumping stations have not been configured, because they only operate during excess water periods. However, in later simulations we will need to model the effects of pumping activities as well, because the stored excess water should be returned to the recipient river.

	Name	Type	No. of Inline structures
1	Nagykunsági	Main canal	1
		West branch	3
		East branch	2
2	Harangzugi	Main canal	1
3	Mezőtúri VI.	Main canal	1
4	Álomzugi	Main canal	1

Table 1. Inline structures in the model

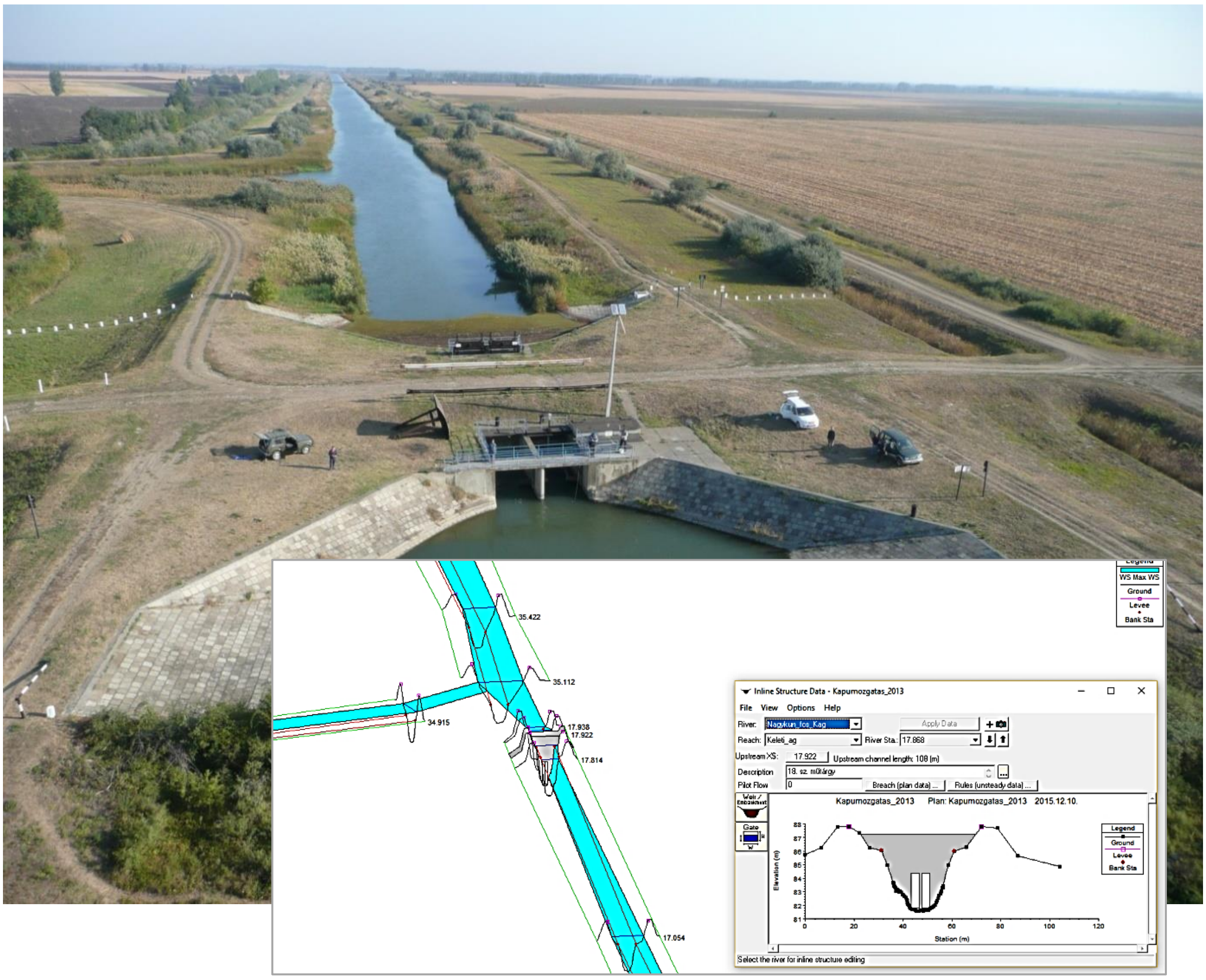

Figure 4. Inline structure

1.4. Boundary conditions

The upper boundary conditions in the model are the flow time-series at Abádszalók, Ágota and Gyoma. Flow data are not derived from discharge gauge, so they aren't actual measurements, but the discharges calculated from different correlation functions(Fig. 5).

The lower boundary condition is the normal depth (Fig. 5). Initial conditions are all constant water level values in the model.

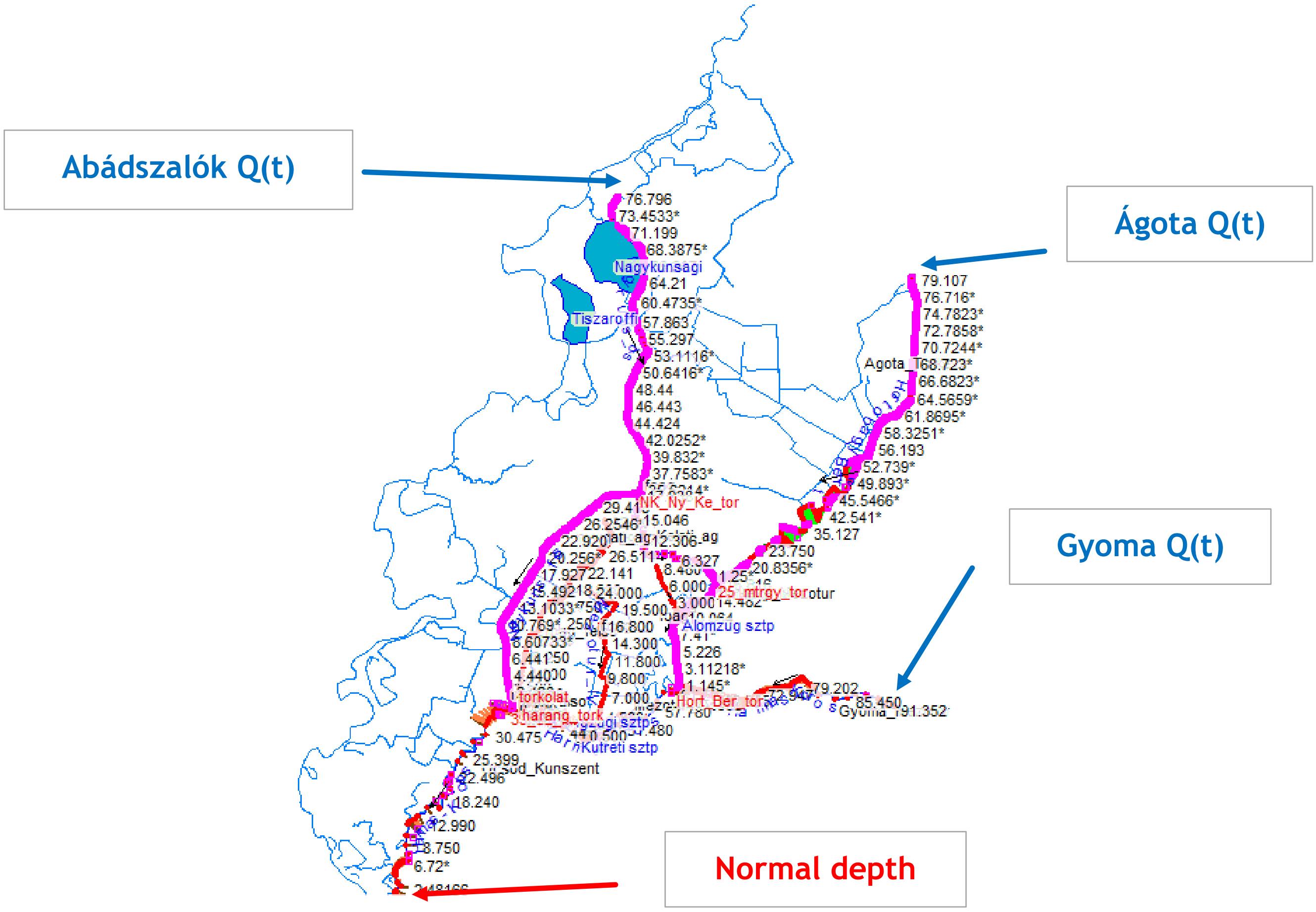

Figure 5. Boundary conditions

1.5. Hydrologic data

Hydrologic data is not relevant for the Hungarian pilot area.

1.6. Hydraulic data

We have chosen a low water period for the calibration of the model. So, we chose the 2012 year for the calibration purpose, because in this year was the biggest drought period in Hungary during the last decade.

At Abádszalók, the average flow was 30 m^3/s in the summer of 2012. Figure 6 clearly shows that the incoming flow was reduced below the average flow by the end of summer. Furthermore, in above period the average flow was 6.5 m^3/s at Ágota (Fig. 7) and 8 m^3/s at Gyoma (Fig. 8).

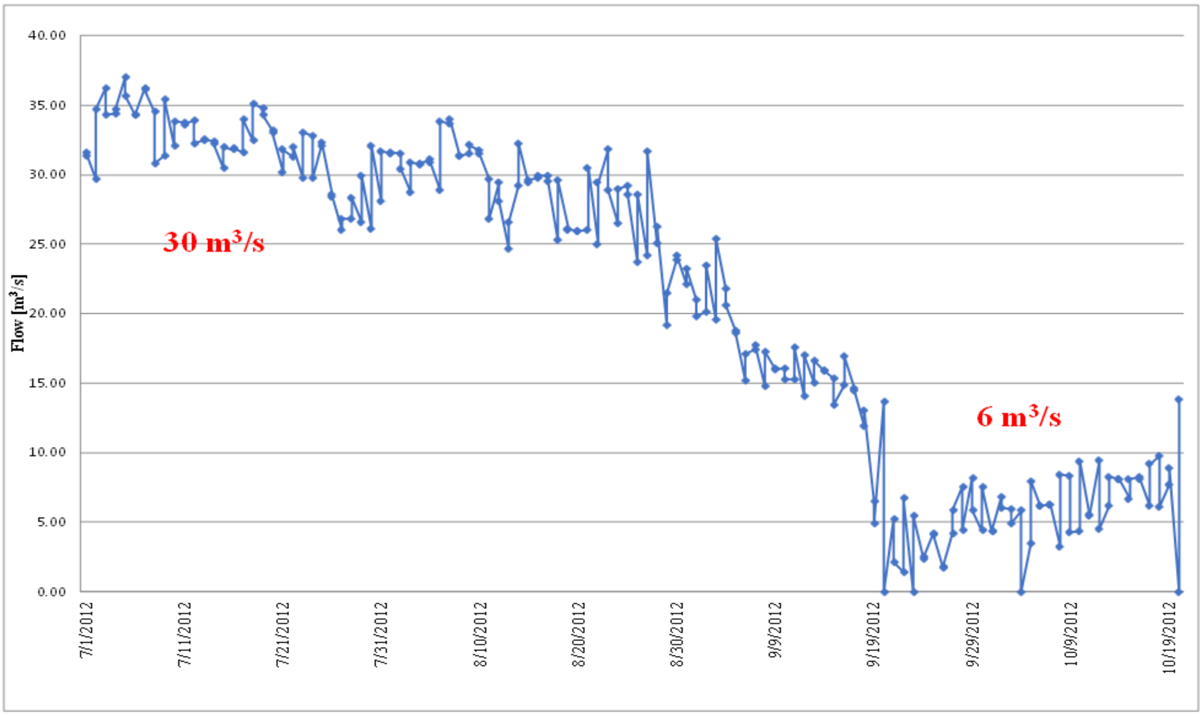

Figure 6. Boundary condition at Abádszalók for the calibration

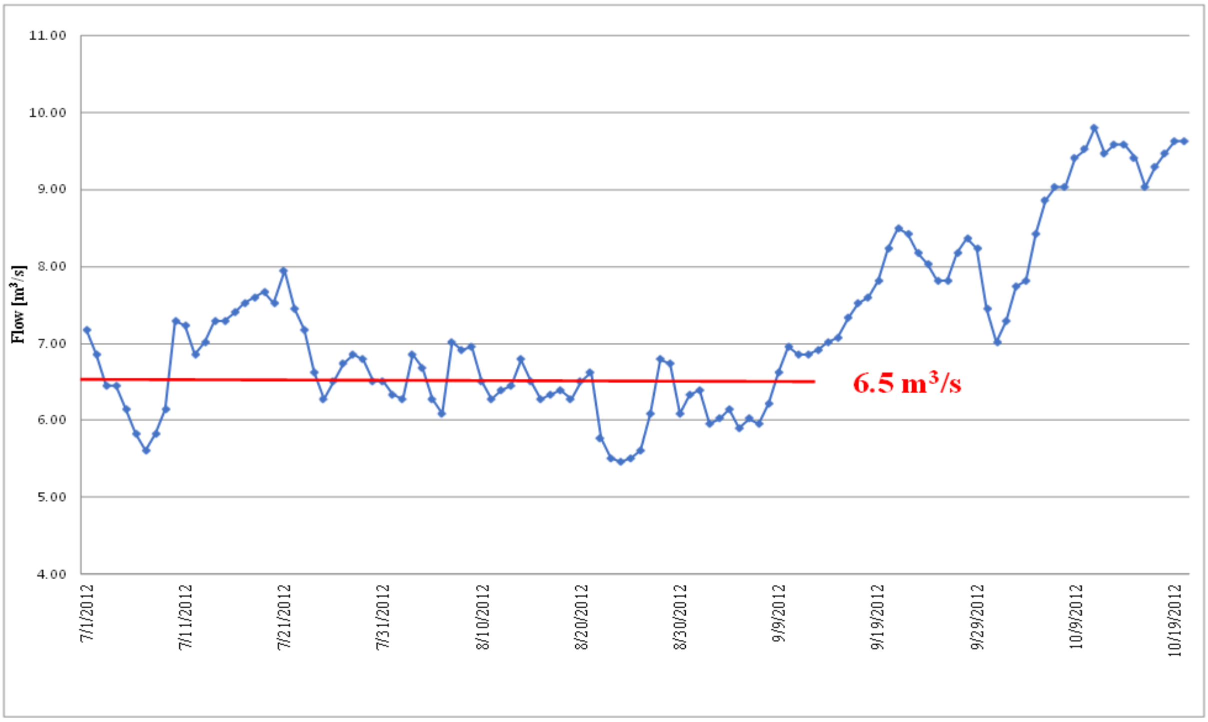

Figure 7. Boundary condition at Ágota for the calibration

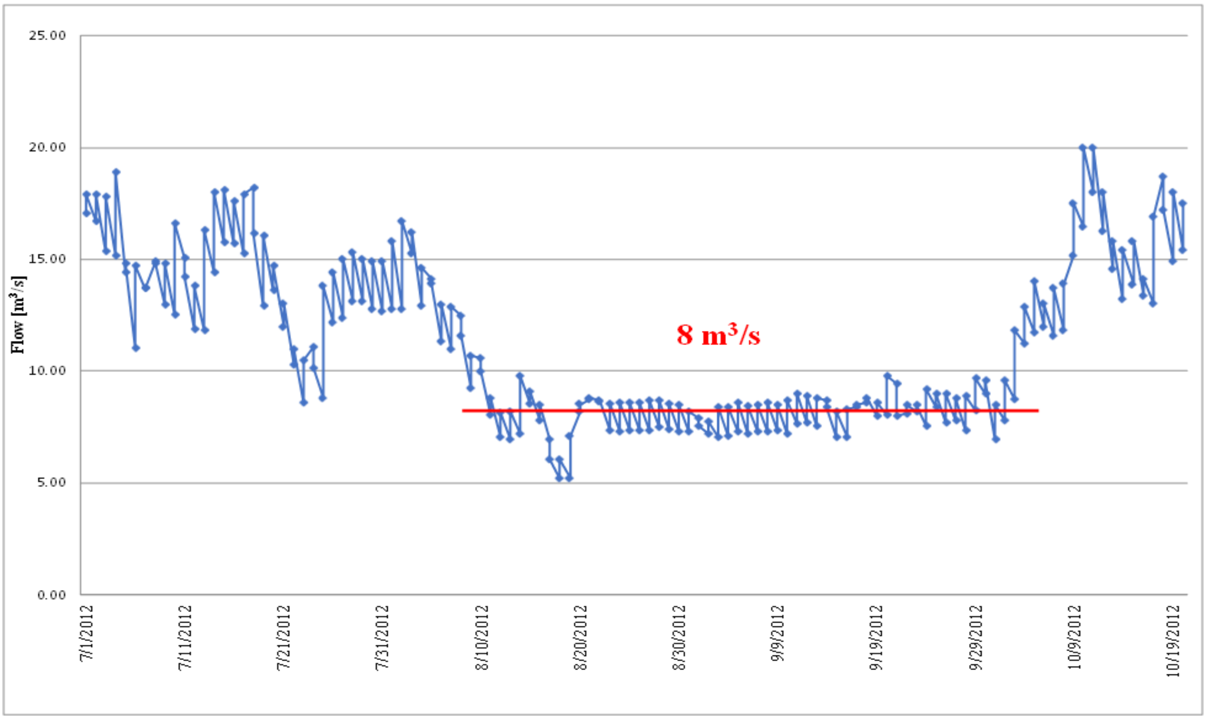

Figure 8. Boundary condition at Gyoma for the calibration

We chose the year 2018 for validation, because in this year was also a drought period in Hungary, but there were smaller floods on Hármas-Körös river, as well.

At Abádszalók, the average flow was 20 m^3/s in summer of 2018 (Fig. 9) and at Ágota the average flow was 7 m^3/s (Fig. 10). At Gyoma the incoming flow reduced 20 m^3/s on the average, that is clearly shown in Figure 11.

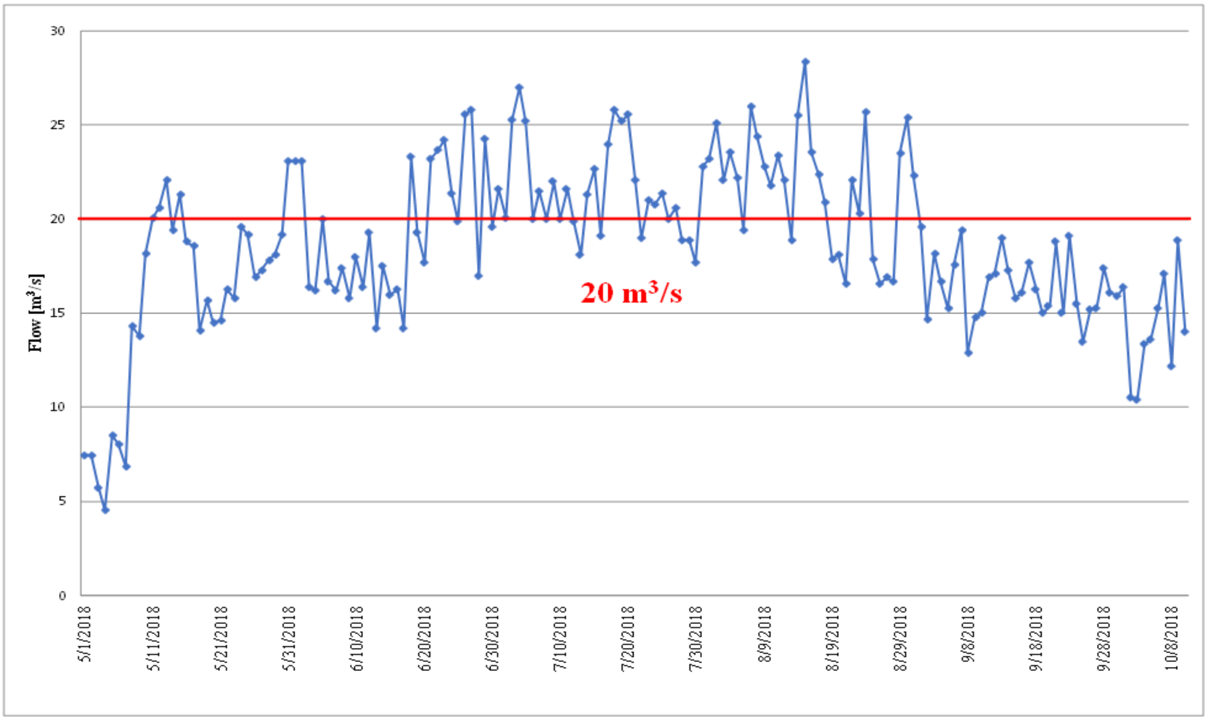

Figure 9. Boundary condition at Abádszalók for the validation

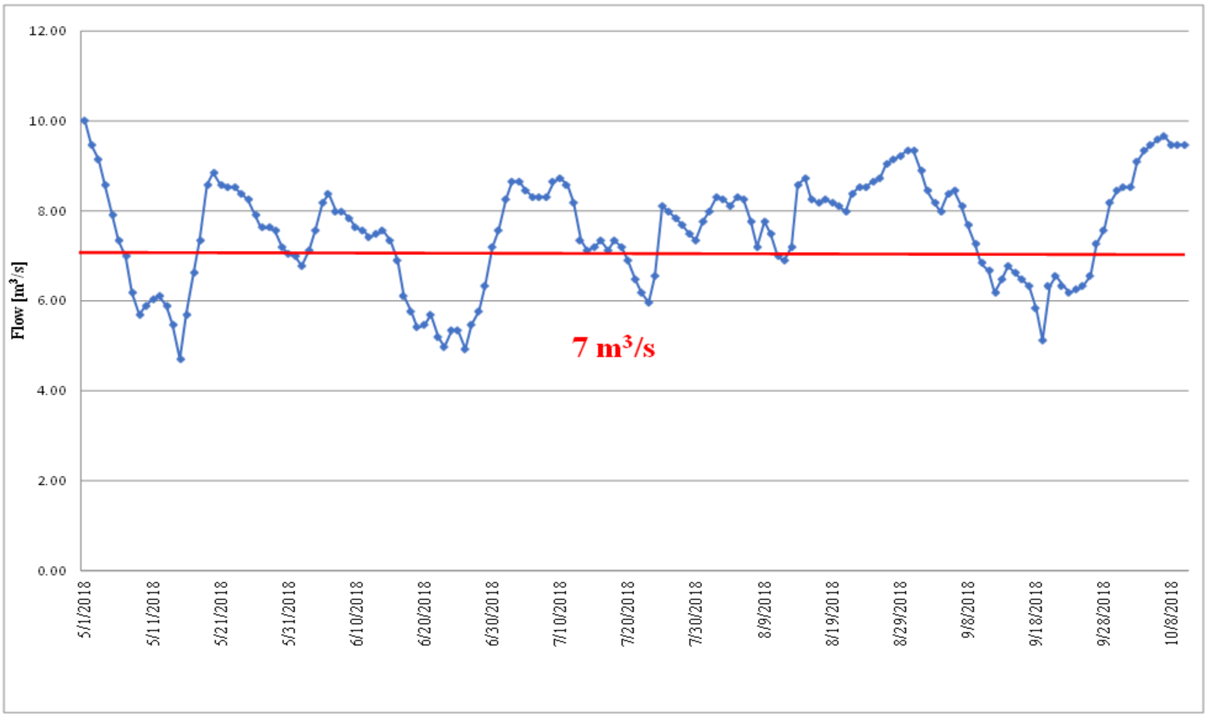

Figure 10. Boundary condition at Ágota for the validation

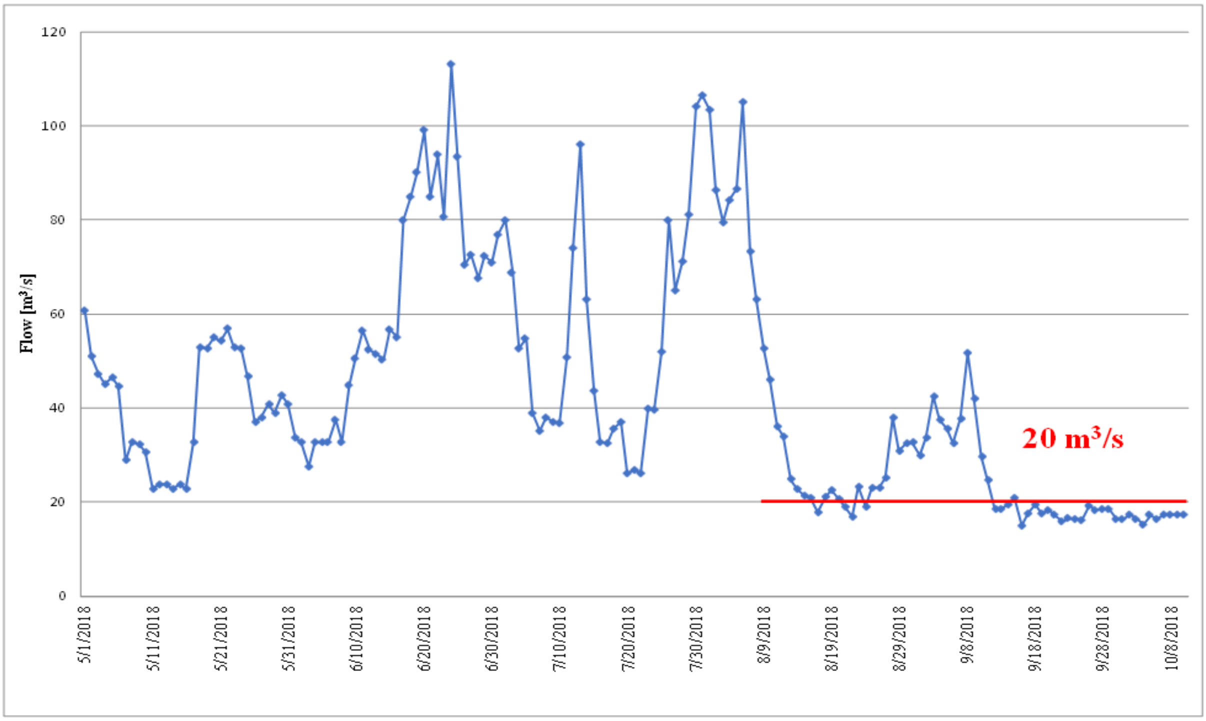

Figure 11. Boundary condition at Gyoma for the validation

We could not calibrate the canals between the west and east branch, because these canals and pumping stations don't operate in dry summer periods.

1.7. Model calibration

The period from 1st July 2012 to 20th November 2012 was used for calibration. There are two calibration points in the main Nagykunsági canal and one in the West and East branchs, separately (Fig. 12). The Figures 13., 14., 15. and 16 demonstrate the differences between modelled and measured water level time series in every calibration cross section. There are positive and negative differences too, because there are a lot of water intakes along the canals. We had monthly quantitative data about irrigation, but we don't know the exact daily usage. Thus, there are many combinations of irrigation water uses, that makes the calibration complicated.

During calibration and validation beginning of the model simulation needs time, that the results become acceptable accuracy. Therefore the following figures show the initial large projections.

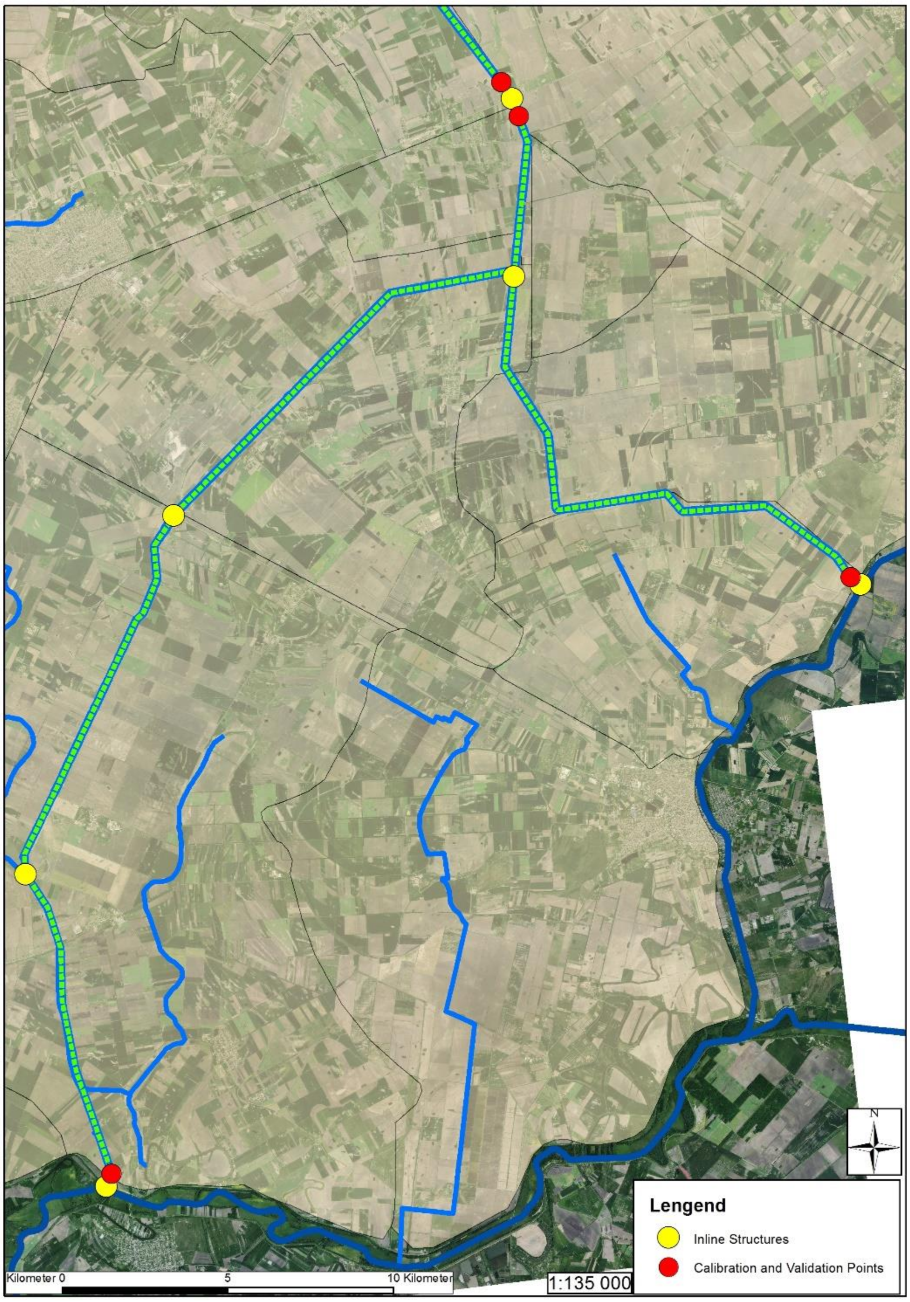

Figure 12. Calibration and validation points

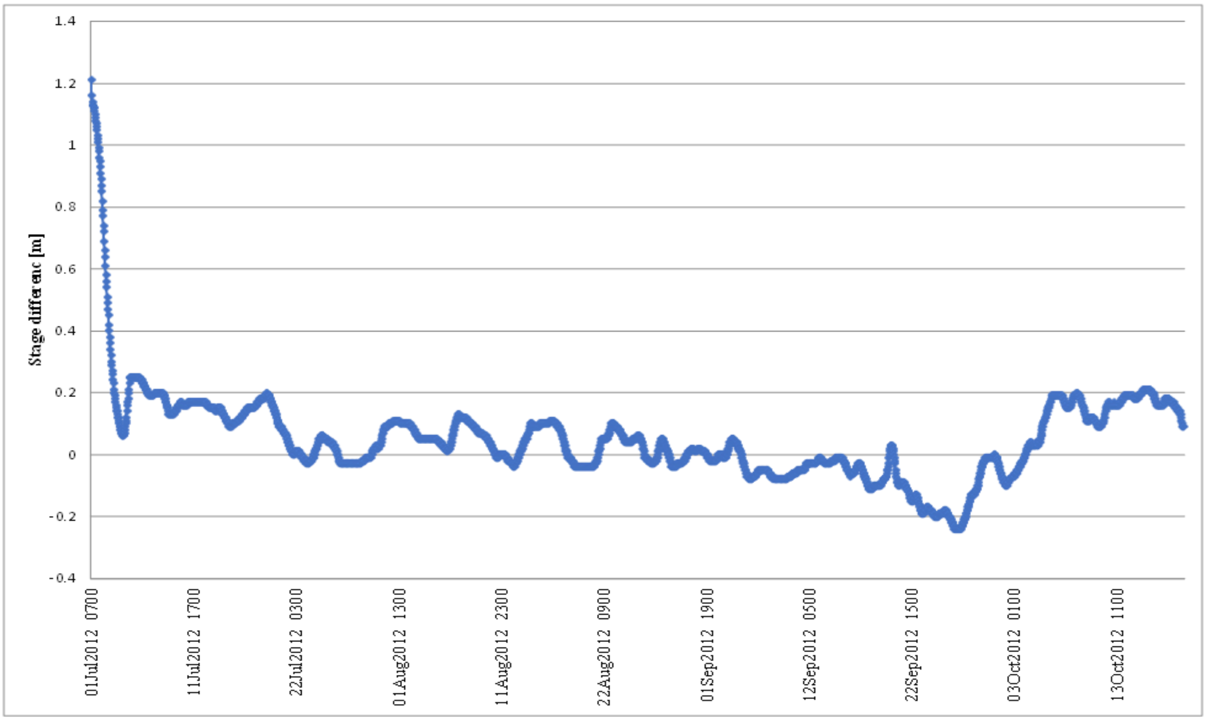

Figure 13. Time series of modelled and measured stage differences at the Nagykunsági Canal (River station: 40.394)

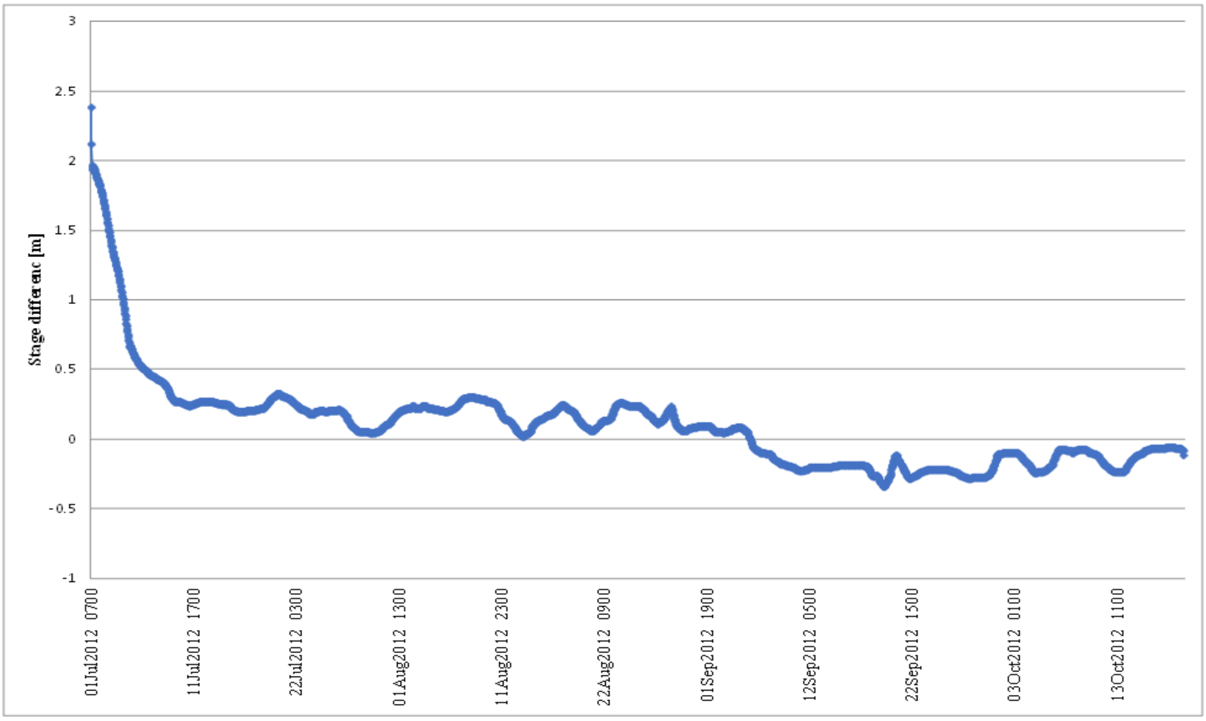

Figure 14. Time series of modelled and measured stage differences at the Nagykunsági Canal (River station: 40.260)

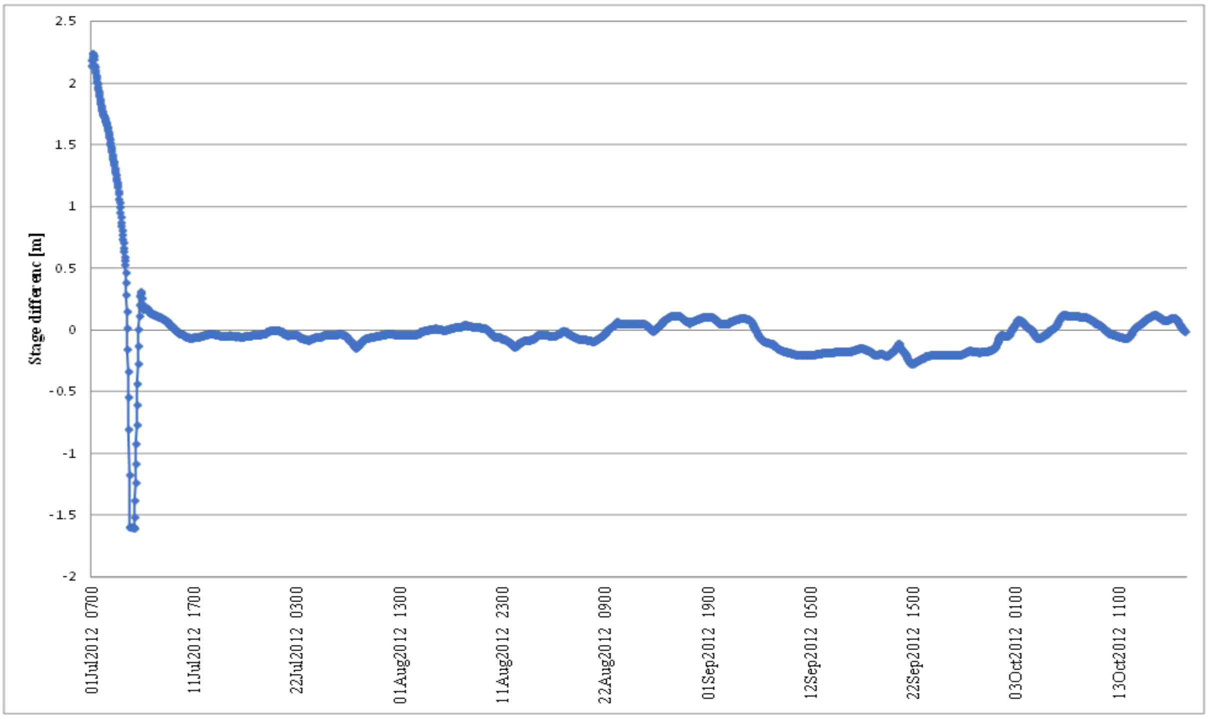

Figure 15. Time series of modelled and measured stage differences at the West branch of Nagykunsági Canal (River station: 0.130)

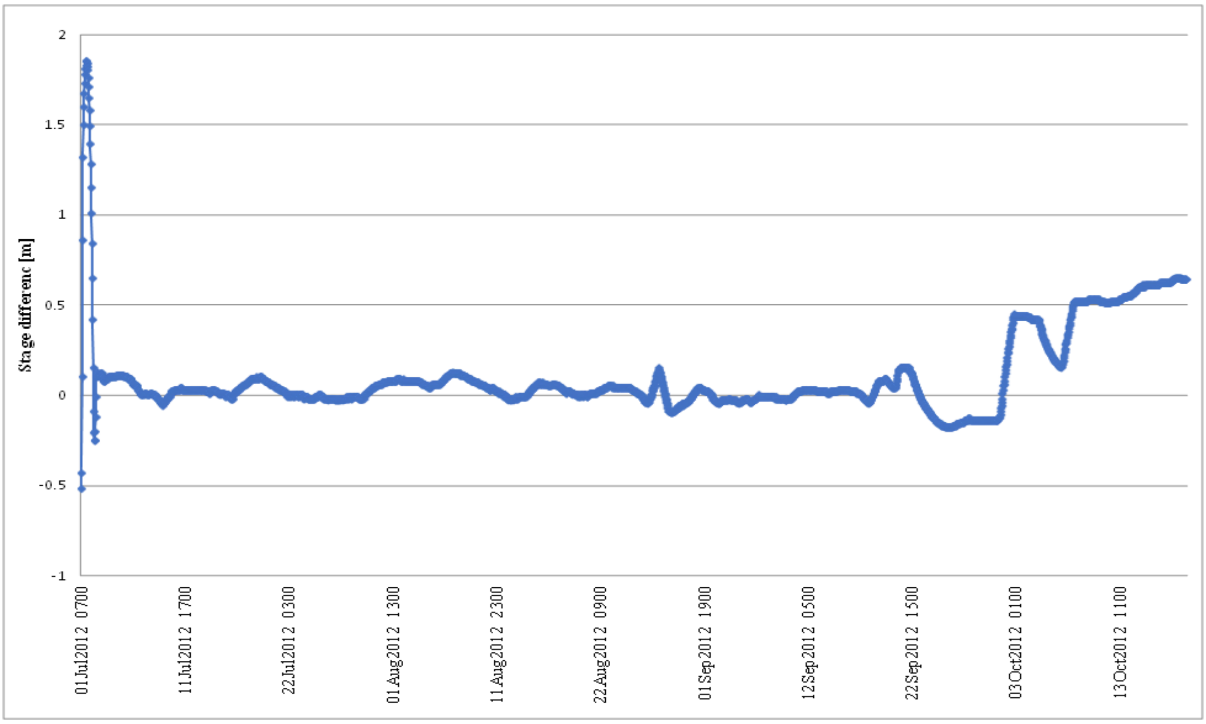

Figure 16. Time series of modelled and measured stage differences at the East branch of Nagykunsági Canal (River station: 0.100)

1.8. Model validation

The validation period was from 1st May 2018 till 10th October 2018. There are two validation points in the main Nagykunsági canal and one on the West and East branchs separately (Fig. 12). The Figures 17, 18, 19 and 20 demonstrate the differences between modelled and measured water level time series in every validation cross section. During the validation positive and negative differences also occurred, but its scale was not significant. So, the result of validation is better than the outcome of calibration.

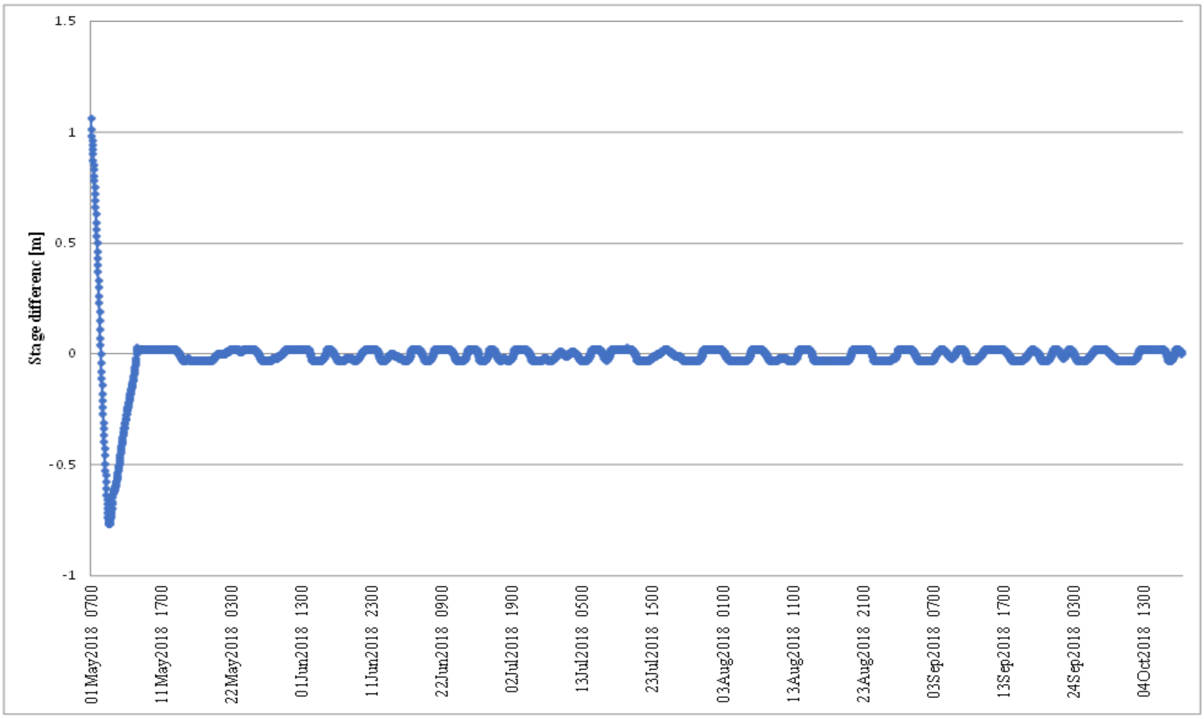

Figure 17. Time series of modelled and measured stage differences at the Nagykunsági Canal (River station: 40.394)

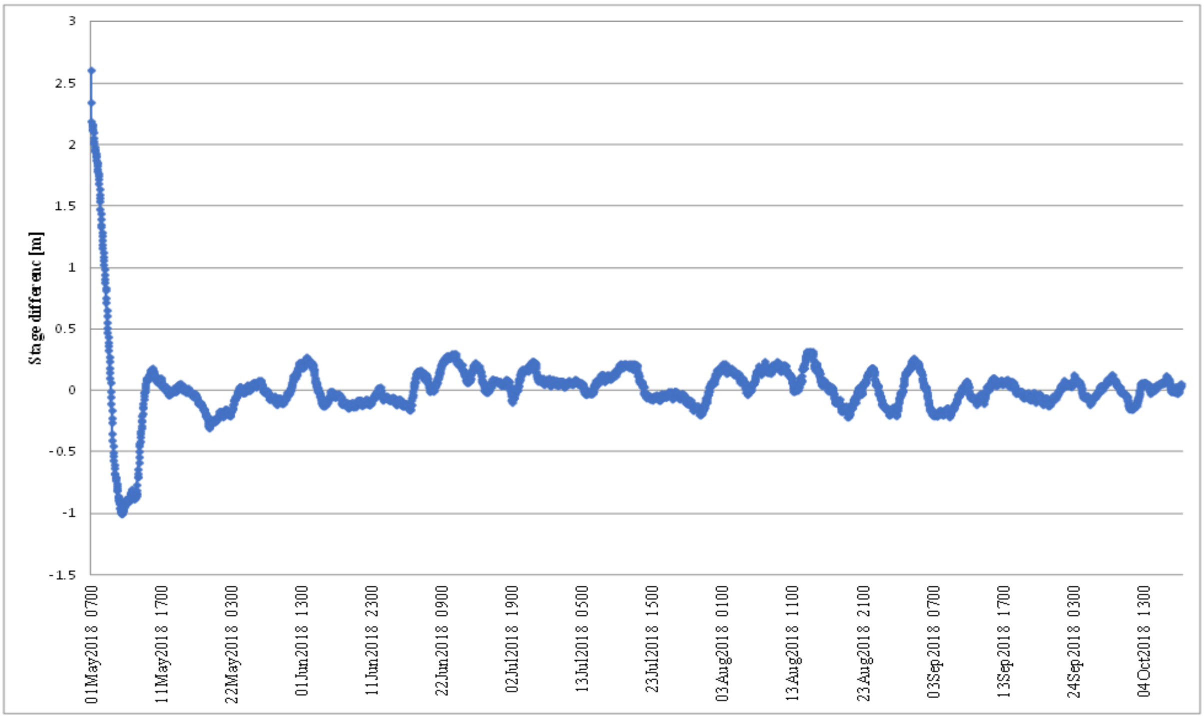

Figure 18. Time series of modelled and measured stage differences at the Nagykunsági Canal (River station: 40.260)

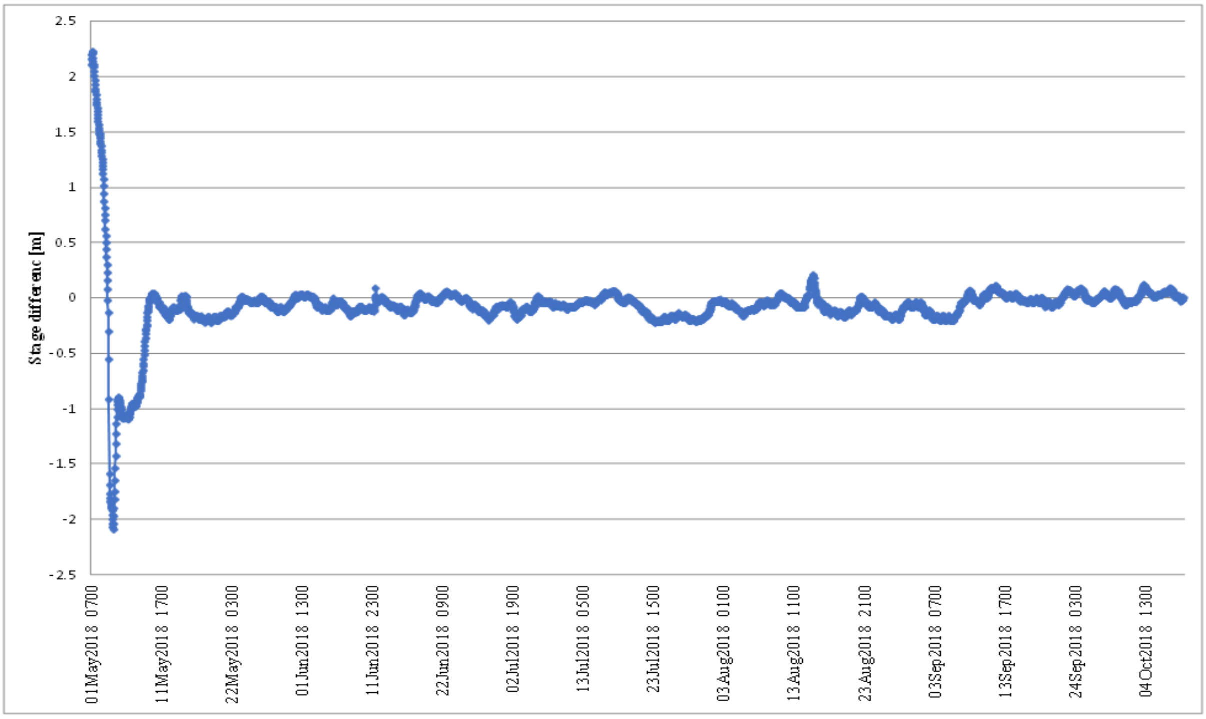

Figure 19. Time series of modelled and measured stage differences at the West branch of Nagykunsági Canal (River station: 0.130)

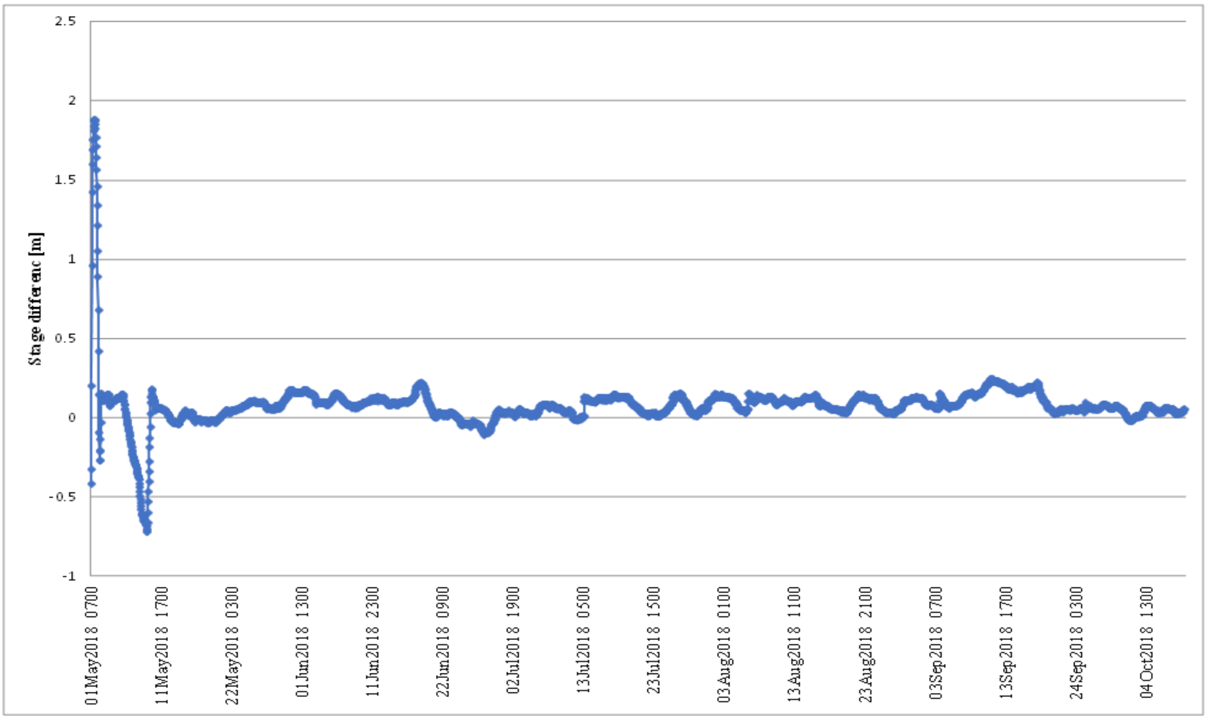

Figure 20. Time series of modelled and measured stage differences at the East branch of Nagykunsági Canal (River station: 0.100)

1.9. Conclusions

The rainfall-runoff hydrological model is not relevant for the Hungarian pilot area, but a hydraulic model for the Nagykunsági canal system could be implemented. The obtained calibration and validation results seem satisfactory thus the model is considered suitable for testing a low-water periods.

2. Results from testing effects of the planned measures with the dynamic model

2.1. Modelling strategy for (N(S)WRM) in the Middle Tisza District Water Directorat pilot area

2.1.1. Introduction of the pilot area

The operative area of the Middle Tisza District Water Directorate (7179,5 km^2) has basically a lowland characteristic and only a part of it has highland profile. The area of the Directorate divided into two parts by the main receiving water body, the River Tisza.

The selected pilot area is situated on the left side of the Tisza River, called the Nagykunsági sub-basin, which is surrounded by the Tisza, Hármas-Kőrös and Hortobágy-Berettyó Rivers (Fig. 21).

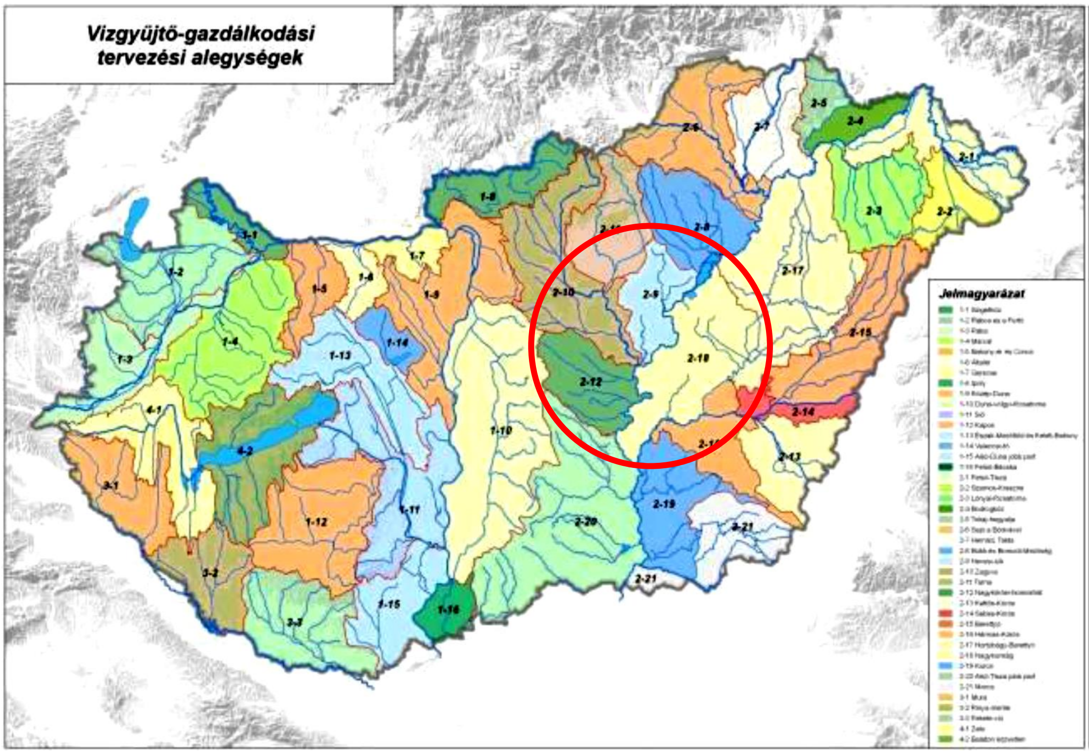

Figure 21. River basin management planning units

After the river regulation works done the 19th century the basin became a closed flat lowland polder surrounded by flood dikes, divided by well-built drainage and irrigation systems.

The main instrument that the water management can use in the sub basin is the Lake Tisza (Kisköre Reservoir), the largest artificial lake in Hungary. This reservoir is the most important element, in terms of water scarcity, in the region. It ensures the average flow of water to the downstream part of Tisza Valley and Kőrös Valley and it provides irrigation water for the Nagykunsági sub-basin.

The area is typically flat and mainly agricultural area with smaller and larger forest patches and some middle and small size settlements.

The pilot catchment area is 2 965 km^2.

The surface water network of Hungary is basically determined by the fact that the country lies in the middle part of the Carpathian Basin. The territorial and temporal distribution of water resources is unequal, excess water and drought periods often follow each otherin the same year.

In the pilot area the main irrigation canal is the Nagykunsági Main canal (Fig. 22).

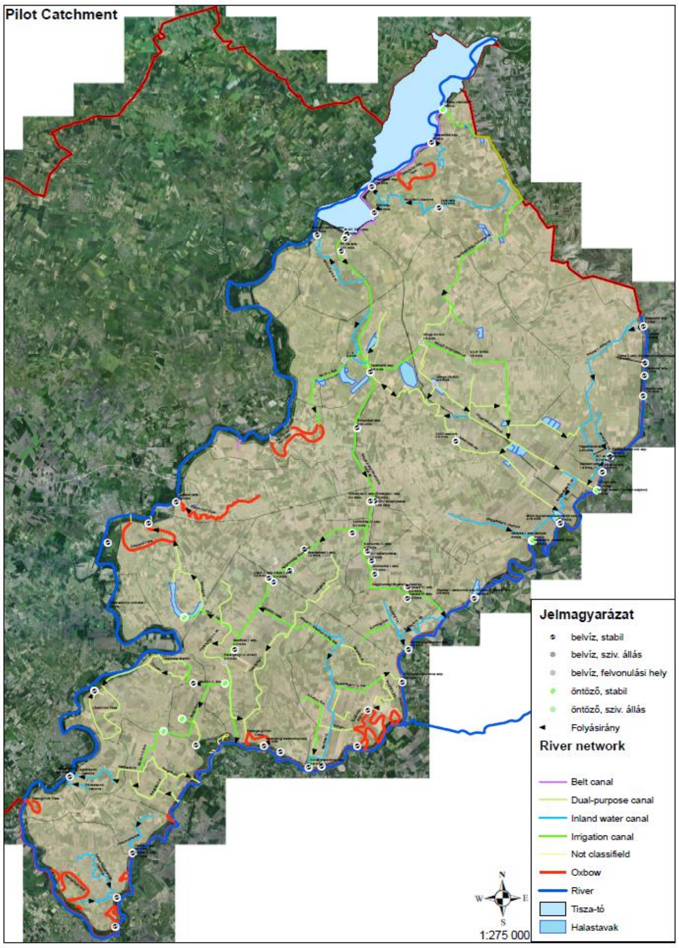

Figure 22. The pilot area

This canal receives water from the Lake Tisza and passes it to the Hármas-Körös and the Hortobágy-Berettyó. The water inflow is around 20-35 m^3/s in the irrigation season (from April to September). The canal is split into two branches near Örményes (at 39.25 rkm). The total length of the Main canal is 74.5 km (including the western branch). The eastern branch is 18.07 km long. The Nagykunsági Main canal flow out from the 144 + 642 km section of the left bank dike of the Tisza, reaches the Hármas-Köröst in the right 33 + 752 km dike section. The Eastern branch of the Nagykunsági main irrigation canal flows out from the Nagykunsági Main canal, reaches the Hortobágy-Berettyó River at the right 16 + 200 km dike section.

The canal connects directly the Lake Tisza and the Körös Valley. (Average annual water volume is 200-250 million m^3.)

This system largely artificially influenced, so in the modelling work we had to take this situation into consideration.

2.1.1.1. Water demand

2.1.1.1.1. Tisza-Körös Valley Water Management System

One of the largest interconnected water management system in Europe is built in the Tisza-Körös-valley between 1940 and 1980. It is called the Tisza-Körös Valley Water Management System (TKVWMS) and the selected pilot area is part of it. The system covers the driest part of the Hungarian Great Plain. The average rainfall in this area is around 500 mm/year, while the potential evapotranspiration is 561.7 mm/year, so year by year droughts used to cause the biggest damage in this area, mostly for the agriculture and the ecosystems.

The main goal of the TKVWMS is to provide water resources from the River Tisza to the Körös Valley and reduce the impact of the water shortage in the Hungarian Great Plain. The Tisza-Körös Valley Water Management System covers an area of 15 000 km^2, which is connected to the operation of four water directorates.

The main instruments of the system are the following:

- 5 river barrages (at Tiszalök, Kisköre, Bökény, Békésszentandrás and Körösladány),
- Main irrigation canals (Nagykunság, Jászság, Kelet and Nyugat),
- Lake Tisza.

The allocation of water resources is the responsibility of four Water Directorates which are situated in the TKVWMS area: Middle-Tisza District Water Directorate (the headquarter is in Szolnok), Trans-Tisza District Water Directorate (Debrecen), Körös-Valley District Water Directorate (Gyula), and Lower Tisza District Water Directorate (Szeged).

Middle-Tisza District Water Directorate is in a special position being responsible for the management of the Kisköre River Barrage, which was put into operation in 1973.

The river barrage can elevate Tisza River by about 11 m, and this water level difference is utilized by the 28 MW hydroelectric power plant located within the barrage and generates 80-110 million kWh of electricity annually. The dynamically renewable water reservoir above the Kisköre River Barrage provides regulated level of water into the lower Tisza River sections, and water into the Körös Valley as well, and ensures directly water for three irrigation systems, namely for Nagykunság (*Fig. 23*), Jászság, and Tiszafüred).

Figure 23. Nagykunság main irrigation canal (Picture source: MTDWD)

The main goals of the system in the pilot area are the following:

- 16 m^3/s water supply for the agriculture, ecology, fish ponds, rice fields with an impact area of 122 435 ha,
- Excess inland water storage from the drainage system,
- Flood wave water transfer from the Hortobágy-Berettyó River to Körös River,
- Fishing utilization of the canals,
- Water supply of oxbow lakes.

There are 7 main inline structures along the Nagykunság main irrigation canal. The water is transferred from the Lake Tisza to the canal at the Nr. 1 structure. The water discharge is formed according to the water requirements of the area. The water level is 88.50±0.05 m (a.s.l.Baltic) at this canal section during an irrigation period. The Nr. 14 structure provides the water retention on the main branch of the Nagykunság main irrigation canal. The inline structure is kept an 87.20±0.05 m water level at the headwater in summer. The Middle-Tisza District Water Directorate can control how much water be transferred to the Western or Eastern branch of the canal with the help of the Nr. 18 structure. The direct water supply of the Hármas-Körös is taken place at the No 39 structure. The water level is around 85.60±0.10 m at the headwater. The water is transferred to the Hortobágy-Berettyó with the help of the Nr. 25 inline structure. The water level is 84,60±0.10 on this canal section. Minimum discharge rates are determined in the Water Restriction Plan (*MTDWD 2018*).

The first water restriction plan for the common TKVWMS was completed in 1993, taking into account the experience from the drought in 1992. Due to the national regulatory changes since 1993, the water restriction plan was updated based on the experiences of the extreme drought years (1992, 1993, 2000, 2002, 2003, and 2007). The plan contains provisions on what measures need to be taken in the various water shortages in terms of the water level of the reservoir, water supply and irrigation water.

2.1.1.1.2. Water restriction measures

In the Middle Tisza region, a water scarcity period is considered when the Tisza's discharge does not reach the 105 m^3/s value above the Tisza Lake. In this case a minimum discharge of 60 m^3/s should be maintained at the river section below the Kisköre Barrage. This flow rate is important to satisfy the water supply needs of Szolnok. The drinking water of the town is provided dominantly by surface water intake from the Tisza River.

During low-water periods, this amount of water can only flow through the barrage of the reservoir - even when water is drained into irrigation systems – if the accumulated water is used from the Tisza Lake. It is possible to prepare in advance for a water deficient period by raising the reservoir's summer water level by 10 cm.

The three stages of the water restriction limit the water supply of the Körös River through the Nagykunság main irrigation canal (Table 2). If the water scarcity gets worse, users should be restricted according to the provisions of water restriction regulations. First, the non-economic water demands are limited. Due to the further deterioration of the defined criteria and the current hydrometeorological forecasts water restrictions have to be taken into effect determined by the Hungarian Water Management Act.

The order of the water restrictions according to the *Hungarian Water Management Act*:

1. non-economic water use (e.g. sport, recreation),
2. economic water use,
3. irrigation water use,
4. natural conversation,
5. fishponds,
6. activity directly serving water supply of the population,
7. drinking water supply, public health, disaster relief.

The agricultural water demands are belonging to the economic use of water. The *Hungarian Water Management Act* determines the ratio of restrictions. The percentage of restriction depends on the cultivation branch. The limit is always calculated from the allowed water volume at every water user.

The agricultural water use must be restricted in the following way, according to the *Hungarian Water Management Act*:

1. Proportional reduction of the water supply of fish ponds, up to 50 %,
2. proportional reduction of the water supply of rice fields, up to 50 %,
3. reduction of the water replacement irrigation by 30 %,
4. further reduction of the water supply of fish ponds by 20 %,
5. proportional reduction of water which is used for irrigation.

I. Stage	
Condition	Discharge to Lake Tisza: Q < 60 m^3/s. Discharge at Kisköre Barrage's upstream: 105 m^3/s > Q > 85 m^3/s. Water level at Kisköre Barrage upstream gauge: 740 cm > H > 725 cm. Discharge at Kisköre Barrage's to downstream section: 80 m^3/s > Q > 60 m^3/s. Water level at Kisköre barrage tail-water gauge: -280 cm > H > -320 cm. Discharge at Szolnok: 80 m^3/s > Q > 60 m^3/s. Water level at Szolnok: -250 cm > H > -280 cm.
Measure	Reducing drained water from Nagykunság irrigatin canal (eastern branch) to Hortobágy-Berettyó River from 14,4 m^3/s to 9,4 m^3/s. Drained water remains 1,6 m^3/s from Nagykunság irrigation canal (western branch) to Hármas-Körös River.
II. Stage	
Condition	Discharge to Lake Tisza: Q < 60 m^3/s. Water level at Kisköre Barrage upstream gauge: 740 cm > H > 725 cm. Discharge at Kisköre Barrage's to downstream section: 70 m^3/s > Q > 60 m^3/s. Water level at Kisköre Barrage tail-water gauge: H = -320 cm. Discharge at Szolnok: 70 m^3/s > Q > 60 m^3/s. Water level at Szolnok: H = -280 cm.
Measure	Reducing drained water from Nagykunság irrigatin canal (eastern branch) to Hortobágy-Berettyó River from 9,4 m^3/s to 6,4 m^3/s. Drained water remains 1,6 m^3/s from Nagykunság irrigation canal (western branch) to Hármas-Körös River.
III. Stage	
Condition	Discharge to Lake Tisza: Q < 60 m^3/s. Water level at Kisköre Barrage upstream gauge: H < 725 cm. Discharge at Kisköre Barrage's to downstream section: Q = 60 m^3/s. Water level at Kisköre barrage tail-water gauge: H = -320 cm Discharge at Szolnok: Q = 60 m^3/s. Water level at Szolnok: H = -280 cm
Measure	Reducing drained water from Nagykunság irrigatin canal (western and eastern branch jointly) to Hortobágy-Berettyó River and Hármas-Körös River to 0 m^3/s

Table 2. Water restrictions in the Middle Tisza Region

2.1.1.1.3. Current water demand

There are several important irrigation systems in the pilot area. The main irrigation systems of the pilot area are the following: Nagykunság irrigation system, Gástyás irrigation system, Tiszafüred irrigation system. The most significant of them is the Nagykunság irrigation system.

The Nagykunság irrigation system consists of additional irrigation sections, which are the following: NK I, NK III, NK IV, NK V-1, NK V-2, NK VII-1, NK X, NK XII. In addition, the water is passed through to further smaller canals.

Based on 2017 water use permits, the main water uses are irrigation, rice plants and fishponds water supply (*MTDWD 2017*). The total annual water demand is 33 million m^3 in the pilot area. *Figure 24* shows the distribution of the water demand.

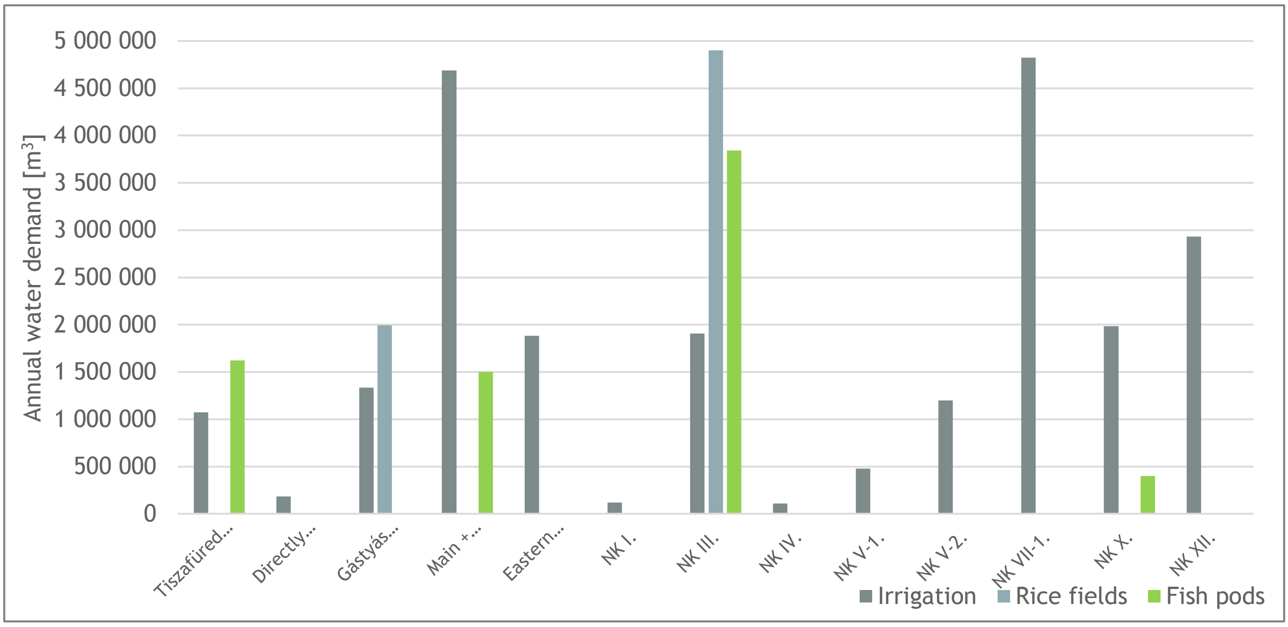

Figure 24. Annual water demand in the pilot area (MTDWD 2017)

2.1.1.1.4. Future water demand

The Hungarian Chamber of Agriculture (HCA) conducted a nationwide water demand survey in 2018. Based on the survey it can be stated that the possible water demand is well above the amount of water currently used in Hungary (*HCA 2018*). The annual average water demand within the pilot area exceeds 55 million m^3, which is expected to increase in the future. *Table 3* shows the distribution of water demand among the irrigation systems in the pilot area.

Irrigation system	Water demand [million m^3]
Nagykunság irrigation system	44.05
Gástyás irrigation system	4.60
Tiszafüred irrigation system	3.33
Directly from Lake Tisza	0.63
Other irrigation systems	3.04

Table 3. Annual average water demand in the pilot area (HCA 2018)

According to the survey, there are 6 474 water use locations. 3 914 are new requests for water, where currently there is no water abstraction. These new demands account for 23 million m^3 water annually, almost half of the total current annual water need in the pilot area.

44 million m^3 water is used directly from the Nagykunság main irrigation canal or its irrigation sections. It can be stated that the Nagykunság irrigation canal has to satisfy large part of the water needs. The water from the Nagykunság main irrigation canal is

distributed to various irrigation sections to reach the users. *Figure 25* shows the water demand in the irrigation sections of the Nagykunság irrigation system.

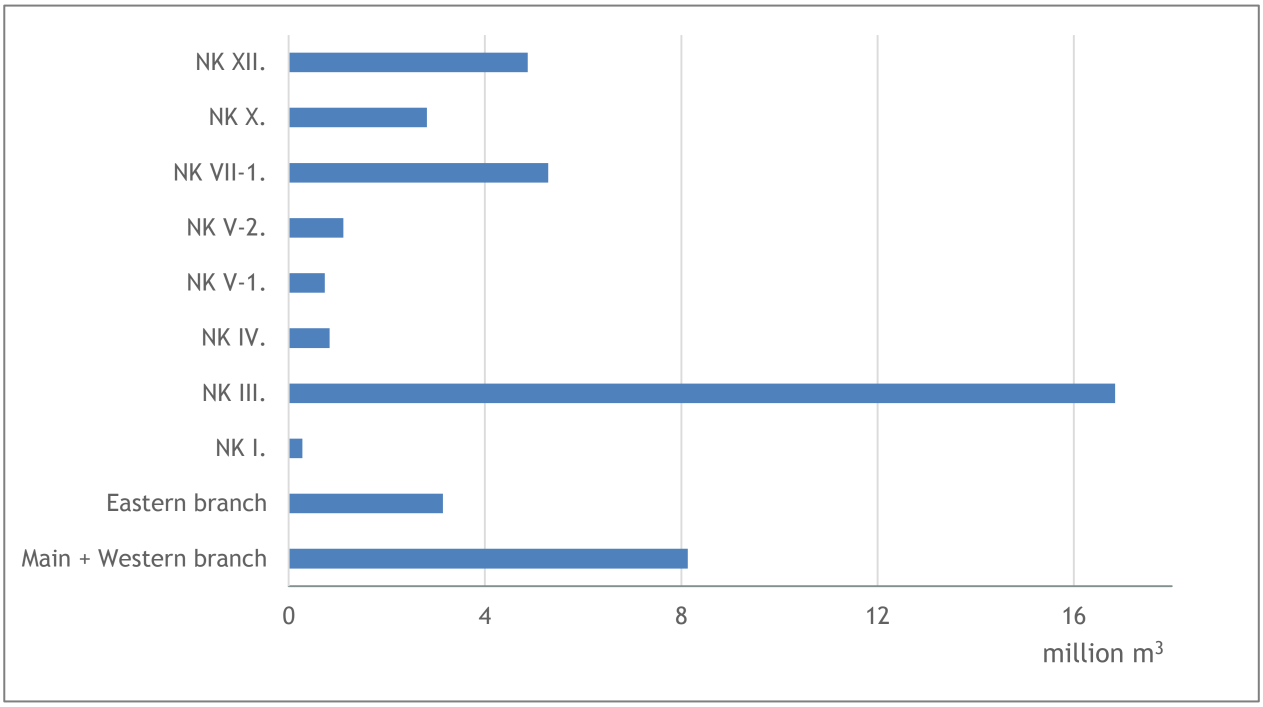

Figure 25. Distribution of future water demand in the Nagykunság irrigation system

It was also necessary to determine how water consumption is distributed during an irrigation period (*Table 4.*). It is highly depends on the hydrometeorological characteristics of a year. In order to determine the distribution between the months, we used the water consumption experiences of the past twenty years. We have assumed that more water supplies are needed in July and August. 65% of the annual water demand is consumpted during these two months. These values are also input data for the hydrodynamic model, when no water restriction measures are needed.

Irrigation section	Annual [million m^3]	May [million m^3]	June [million m^3]	July [million m^3]	August [million m^3]	September [million m^3]
Main + Western branch	8.14	0.41	1.22	2.44	2.85	1.22
Eastern branch	3.14	0.16	0.47	0.94	1.10	0.47
NK I.	0.28	0.01	0.04	0.08	0.1	0.05
NK III.	16.84	0.84	2.53	5.05	5.90	2.52
NK IV.	0.83	0.04	0.13	0.25	0.29	0.12
NK V-1.	0.73	0.04	0.11	0.22	0.25	0.11
NK V-2.	1.11	0.06	0.17	0.33	0.38	0.17
NK VII-1.	5.29	0.26	0.80	1.59	1.85	0.79
NK X.	2.81	0.14	0.42	0.84	0.99	0.42
NK XII.	4.87	0.24	0.73	1.46	1.70	0.74

Table 4. Distribution of water demand in the irrigation sections

2.1.1.2. Water quality

Regular water quality measurements are carried out in 9 locations in the pilot area (e.g. locations on the Nagykunság main irrigation canal). Measurements are also made on four smaller canals, and they are performed monthly by the MTDWD.

When classifying water bodies under the *WFD*, classification is made in different groups: biological, hydro morphological, and physical-chemical characteristics. Based on the results of the measurements, the Nagykunság main irrigation canal's water quality was excellent in the last years (*Table 5*).

Component	dimension	Water quality limits						Water body's value			Qualification				
		excellent / good	excellent / good	good / medium	good / medium	medium / weak	weak / bad	minimum	maximum	average	excellent	good	medium	weak	bad
pH	(-log[+])	7	8.5	6.5	9	9.5	10	7.38	8.40	7.94	5				
Specific conductivity	(μs/cm)	0	600	0	900	3000	5000	296	467	395	5				
Chloride ion	(mg/L)	0	40	0	60	300	500	17.0	46.0	31.7	5				
Dissolved oxygen	(mg/L)	8	0	7	0	4	3	3.8	9.9	7.3		4			
BOI_5	(mg/L)	0	3	0	4	15	25	0.6	1.9	1.1	5				
KOI_{Cr}	(mg/L)	0	15	0	25	50	75	9.6	21.0	14.8	5				
Ammonium-N	(mg/L)	0	0.2	0	0.4	2	5	0.010	0.1	0.030	5				
Nitrite-N	(mg/L)	0	0.03	0	0.06	0.3	1	0.004	0.016	0.008	5				
Nitrate-N	(mg/L)	0	1.5	0	2	25	50	0.130	0.4	0.266	5				
Total-N	(mg/L)	0	2.5	0	3	30	55	0.640	1.8	1.158	5				
Orthophosphate-P	(μg/L)	0	80	0	120	700	1500	5	30	11	5				
Total-P	(μg/L)	0	150	0	250	1000	2000	25	130	40	5				

Table 5. Water quality of the Nagykunság irrigation canal in 2017

In natural water bodies problems with water quality are most likely to occur during low water periods. In this case sewage disposal or excess nutrient load from agriculture can cause problems with water quality. Untreated sewage disposal can also cause problem on canals with low discharge, for example which are used to drain excess water. According to the water quality results, Nagykunság main irrigation canal does not have this kind of problem.**During the data collection work, high salt concentration was found in the Harangzugi main drainage canal, so the water quality part of the assessment examine the possibilities to reach a better water quality status.**

2.1.2. Modelling N(S)WRM with HEC-RAS 1D model

In the pilot catchment of Middle-Tisza District we used HEC-RAS 1D model to evaluate the hydrodynamic and water quality effects of the planned measures. Due to the design of the HEC-RAS model, we do not have the opportunity to examine all the planned measures.

HEC-RAS 1D model can be used to analyse the hydro-dynamic conditions of the watercourse or water quality change.

Measures can be assessed using 1D HEC-RAS model in river basin according to the Concept plan of MTDWD in FramWat project *(Table 6)*:

2.1.2.1. Surface Excess water storage

Excess water surface storage in field, in existing drainage canal system and oxbows, and former wetlands.

Related measures:

- **N02 Wetland restoration and management**
- **N07 Reconnection of oxbow lakes and similar feature**
- **A01 Meadows and pastures (Meadow and pasture areas tolerate periodic flooding caused by pluvial floods, moreover excess water can increase grass yields)**
- **D01 Regulated outflow from drainage systems**
- **D02 Water damming in ditches, wires with constant crest (valleys)**
- **D03 Active water management on a drainage system (river valleys)**
- **D04 Construction of micro reservoirs on ditches**
- **D07 Construction of reservoirs on outflows from drainage systems**

The modelling activity focused on the effects of excess water retentions to the flood waves. In flood and pluvial flood situation the excess water drained by the drainage canal system. The drainage process only works with pump stations (68 pieces) using the complex drainage canal system of the pilot river basin.

Observed data from previous pluvial flood situation were used to determine the amount of retained excess water.

We couldn't analysed directly the effects of the measures with 1D hydrodynamic model. In the following paragraphs describe how to calculate the water quantity impact of each measure on SPUs. The calculated amounts of water were taken into account in the model with pumping or water demand, which increases or decreases the amount of water to be drained.

2.1.2.2. Soil water retention

Increasing soil water retention capacity by loosening soil structure, using appropriate agricultural technique (deep plowing/deep ripping).

The criteria for selection of the area for deep plowing (ripping) were:

- Good quality arable,
- High risk of pluvial flood.

As a result of loosening the condition of the original soil with 36-39% of total pore volume may change to 50-65%. (doi:10.2136/sssaj2007.0122)

The assumption was that the deep plowing cause increase of 5% pole volume in 0.4 m depth, so we could calculate the water retention capacity of this kind of area using that kind of cultivation in every SPU.

Related measures:

- A01 Deep plowing/Deep ripping (Measure A15)

The amount of water stored in the soil structure is not drained, therefore it is possible to model the effect of reduced water volume on river discharge-water conditions.

Code	Measures
A15	Deep plowing (removing the plow's sole)
N02	Wetland restoration and management
N07	Reconnection of oxbow lakes and similar feature
A01 **D01**	Meadows and pastures Regulated outflow from drainage systems
D02	Water damming in ditches, wires with constant crest (valleys)
D03	Active water management on a drainage system (river valleys)
D04	Construction of micro reservoirs on ditches
D07	Construction of reservoirs on outflows from drainage systems

Table 6. Planned measured to examine with 1D HEC-RAS model

2.2. Effects of excess water storage on floods level

In Chapter 2.1.2.1 and 2.1.2.2 described water retentions effect of flood wave of recipients Tisza, Hármas-Kőrös, Hortobágy-Berettyó rivers.

Table 7. shows the amount of water retained by the measures calculated for the SPUs using the methods mentioned in the previous paragraphs. These quantities were used in the hydrodynamic modell:

No	SPU	Code	Excess water storage in M/P (1000 m³)	Excess water storage in planned M/P (1000 m³)	Deep plowing (em³)	Storage in drainage canal system (1000 m³)	Oxbows (1000m³)	TOTAL (1000m³)
1	Mezőtúr-Halásztelki	62c	11	205	99	11	650	976
2	Túrkevei-Kiserdei	62a	50	58	102	21	0	231
3	Kakati	61c	92	477	89	350	0	1007
4	Villogói	61b	160	0	846	204	0	1211
5	Karcagi	61a	116	0	512	348	0	977
6	Álomzugi	62b	2	215	82	64	0	362
7	Tiszabői	60d	48	63	18	56	0	185
8	Mirhó-Gyólcsi	60a	19	0	114	86	0	220
9	Ledencei	60b	10	0	0	0	0	10
10	Tólaposi	60c	50	7	2	8	0	66
11	Örményes II.	63c	0	50	6	0	0	57
12	Örvényabádi	59	219	0	295	116	0	630
13	Mesterszállás-Bartapuszta	63a	3	40	250	215	400	908
14	Szenttamási	63b	4	108	184	0	0	296
15	Örményes I.	62d	0	2	24	0	0	26
16	Rákóczifalva-Szandai	64e	0	0	0	7	0	7
17	Alcsi-Tenyő-Kengyeli	64d	1	37	15	13	600	666
18	Fegyvernek-Büdöséri	64a	33	16	5	9	500	563
19	Szajoli	64c	20	29	16	36	600	701
20	Óballai	64b	2	19	0	7	0	27
21	Németéri	49a	110	0	82	87	0	278
22	Kungyalu I.	66b	8	1	16	21	0	46
23	Cibakházi	65a	5	0	0	53	700	758
24	Tőkefoki	66d	7	0	3	35	400	445
25	Tóközei	66c	45	0	0	16	0	60
26	Tiszaugi	65c	5	0	0	10	70	85
27	Kungyalu II.	66a	0	0	2	8	0	10
28	Tiszakürti	65b	3	43	22	20	0	88
	Sum:		1 024	1 369	2 785	1 798	3 920	10 897

Table 7. Total amount of pluvial flood storage in Pilot catchment

In flood situation when the recipients water level higher than protected field surface, the drainage process only works with the well-built drainage canal system and pump stations, the pumping activities have a great influence to drain because of the low slope of the canal.

Flood situation in Tisza and Hármas-Körös Rivers mainly depends on upper parts of the catchment’s hydro meteorological conditions. The effects of pumping the excess water from the pilot area to the main recipients (Tisza and Hármas-Körös) is small on these rivers, but exception is the Hortobágy-Berettyó River, which drain the biggest amount of excess water, but the waterflow capacity of the river is the lowest.

So, the modelling work focused on the Hortobágy-Berettyó River, and analysis was carried out using a real flood situation in winter 2010-2011. During the modelling process the assumption was that the water stays in land, drainage canal and oxbows with the measures we planned, the necessary pumping activity decrease. We calculated the water levels in Hortobágy-Berettyó during the flood period with pumping and we subtracted retaining water of the cumulative effects from the pumping quantity. After that we analysed the water levels in Hortobágy-Berettyó during the flood period with reduced pumping.

The critical section of the Hortobágy-Berettyó floods is in the area of the city of Mezőtúr. Figure 26 shows the water level and discharge time series of the Mezőtúr section. We can clearly see that in this cross section we can decrease by about 10 cm the maximum water level with the planned measures. Furthermore, the available maximum water level is decreased by about 20 cm along the Hortobágy-Berettyó, what we can see in the longitudinal profile in Figure 27. It can be said that the planned measures are important in terms of flooding.

Legend to Figures 26 and 27:

- flood: the results in Hortobágy-Berettyó during the flood period with pumping
- flood_cumlative: the results in Hortobágy-Berettyó during the flood period with reduced pumping

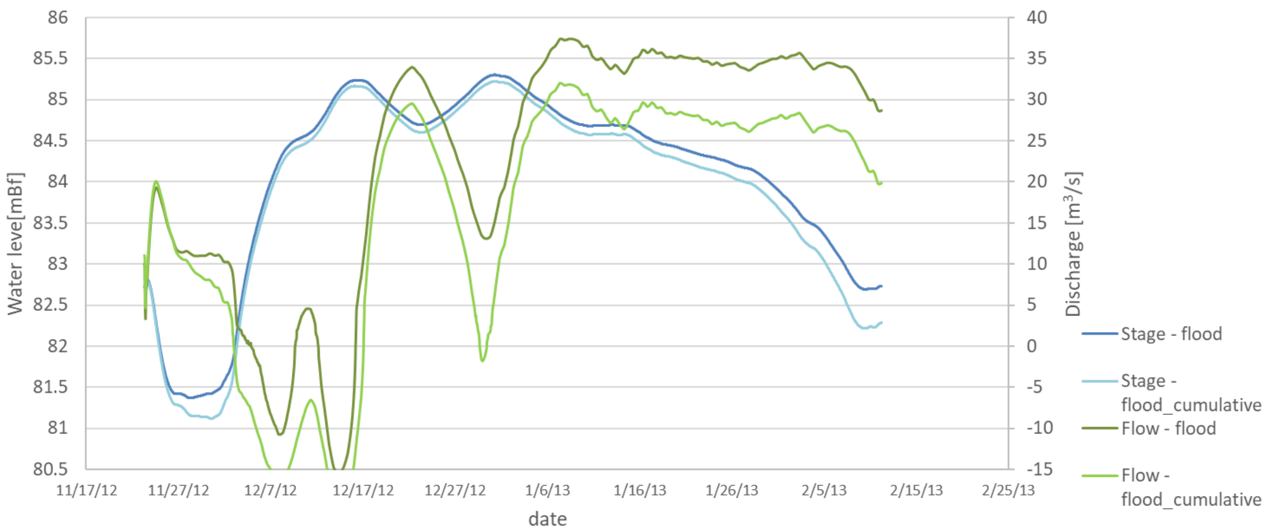

Figure 26. Cross section results in Mezőtúr

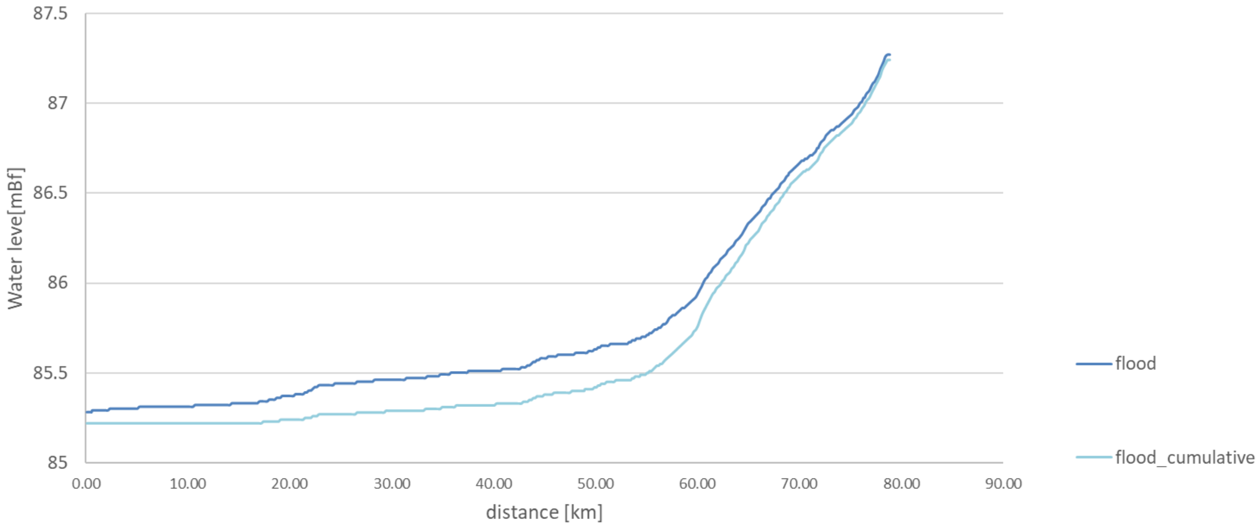

Figure 27. Longitudinal profile in Hortobágy-Berettyó

2.3. Effect of increasing water demands on drought period

The Hungarian Chamber of Agriculture (HCA) conducted a nationwide water demand survey in 2018. Based on the survey it can be stated that the possible water demand is well above the amount of water currently used in Hungary (HCA 2018).

The modelling work focused on Nagykunsági canal, the analysis was carried out using a real drought situation in Summer 2012.

The modelling question was whether expected water demand from the survey and TIKEVIR regulation can be achieved together.

We calculated the water levels and discharges in Nagykunsági canal during the drought period with the present water demands, after that we analysed the drought situation in Nagykunsági canal with the future water demands.

Figures 28 and 29 show the water level and discharge time series for the end sections of the west and east branches.

During the simulation, using TIKEVIR regulation (Tisza-Körös-valley common water management system) we have to take to Hármas-Körös 1.6 m3/s through the Nagykunsági west Branch and to Hortobágy-Berettyó 14.4 m3/s through the East Branch.

Figure 28 shows that due to the future water demand, the water level in the west branch decreased by half meter to the last third of simulating period and in this time there was no any extra water discharge use. The east branch also produced similar results.

Conclusion: The expected water demands cannot be guaranteed in the future during irrigation period with these conditions.

Legend to Figures 28 and 29:

- drought: the results in Nagykunsági during the drought period with the present water demands
- drought_nak: the results in Nagykunsági during the drought period with the future water demands

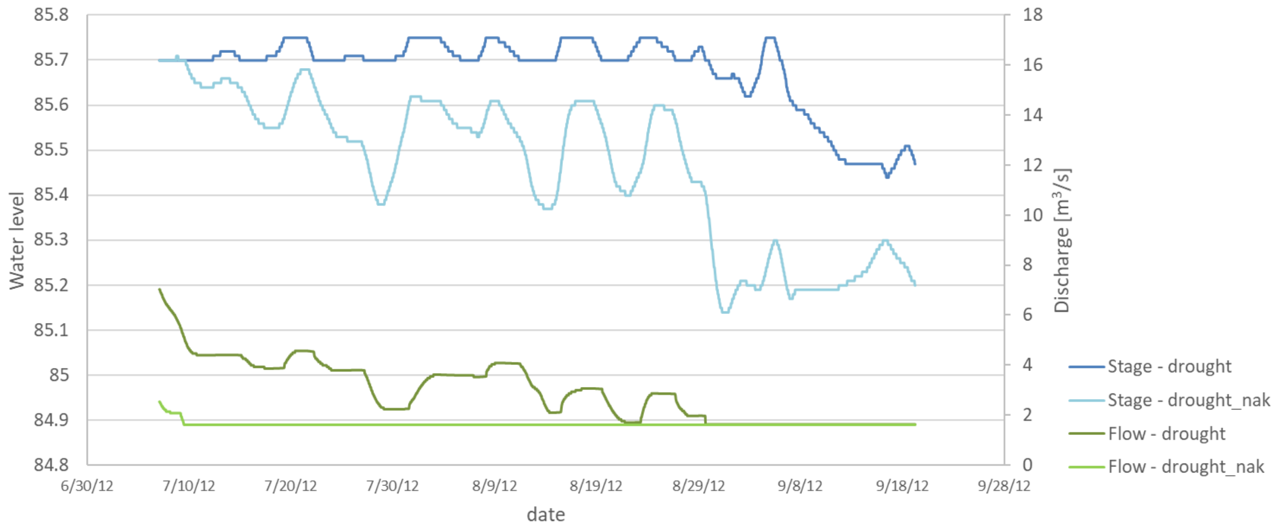

Figure 28. Cross section results end of the West Branch

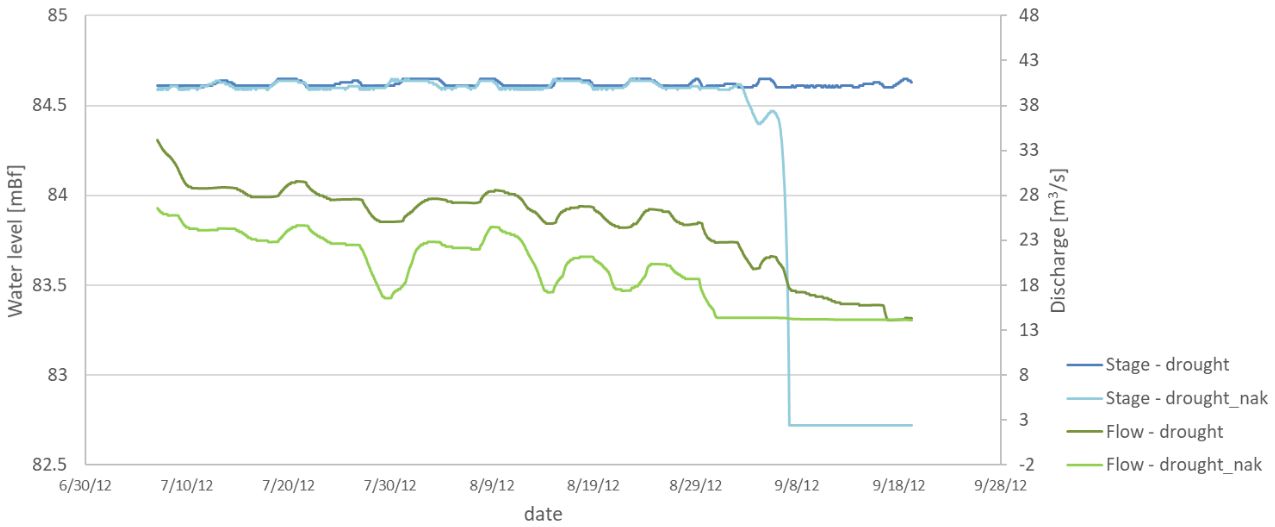

Figure 29. Cross section results end of the East Branch

2.4. Effect of canal storage for increasing water demands on drought period

As a result of climate change there is a growing demand for water which needs to be handled, because it could be unsustainable in the future.

Related measures:

- D02 Water damming in ditches, wires with constant crest (valleys)
- D03 Active water management on a drainage system (river valleys)

The first solution we considered to examine and assess was the canal storage in canal bed.

So the modelling work focused on Nagykunsági canal, the analysis was carried out using a real drought situation in summer 2012.

The modelling work focused on the effect of raising the operating water level by half and one meter.

At first, we raised the operating water level by half meter and analysed the drought situation in Nagykunsági with the future water demands, after that we increased the stage of canal by one meter and calculated the results in Nagykunsági canal with the future water demands.

The Figures 30, 31 and 32 show the water level and discharge time series for the end sections of Main canal, the west and east branch. Modelled results of the Main canal derive from upper side of outlet structure. During the simulation we can take to Hármas-Körös 1.6 m3/s through the Nagykunsági west Branch and to Hortobágy-Berettyó 14.4 m3/s through the East Branch (TIKEVIR regulation).

The Main canal shows that the half meter rise in water level is achieved, but there is no additional usable water flow and raising it by one meter produces additional usable water flow, but the water level cannot be retained for the last third of the simulation period. In the western branch, higher water levels cannot be retained from the beginning of the period. In the east branch the water level decreased to the last third of simulating period and in this time it have not any extra using water discharge.

The conclusion is that only the water level raising is not enough. Without increasing inflows, we cannot achieve effective results by raising the water level of the canal.

Legend to Figures 30, 31 and 32:

- drought: the results in Nagykunsági during the drought period with the present water demands
- drought_nk_+05: the results in Nagykunsági during the drought period with the future water demands (increased water level by half a meter)
- drought_nk_+1: the results in Nagykunsági during the drought period with the future water demands (increased water level by one a meter)

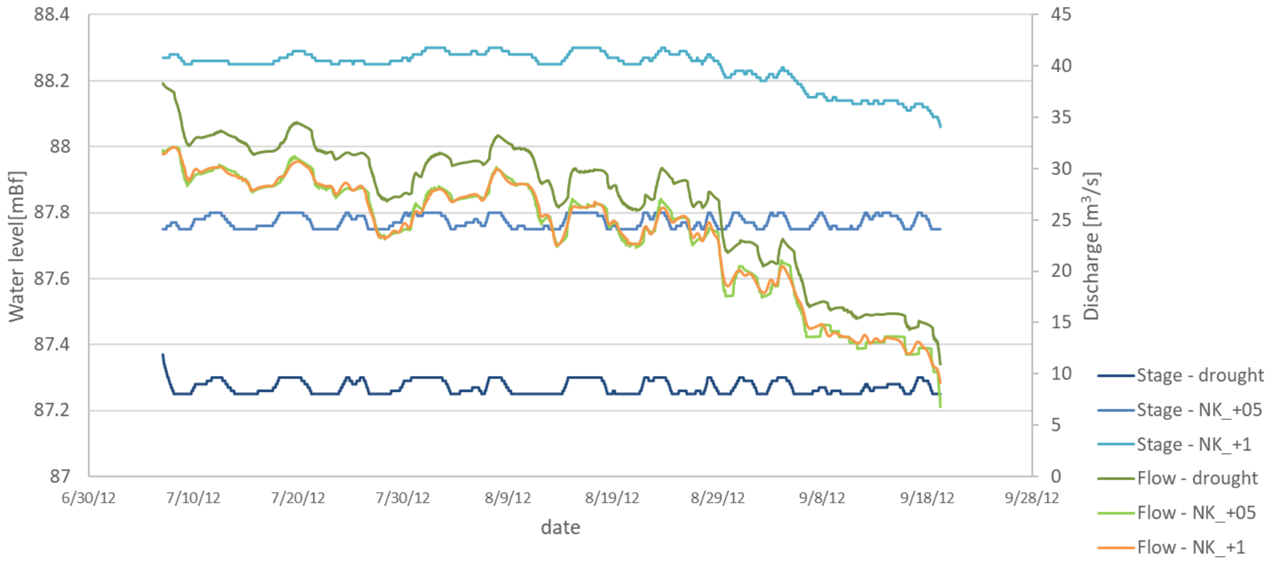

Figure 30. Cross section results of the Main canal

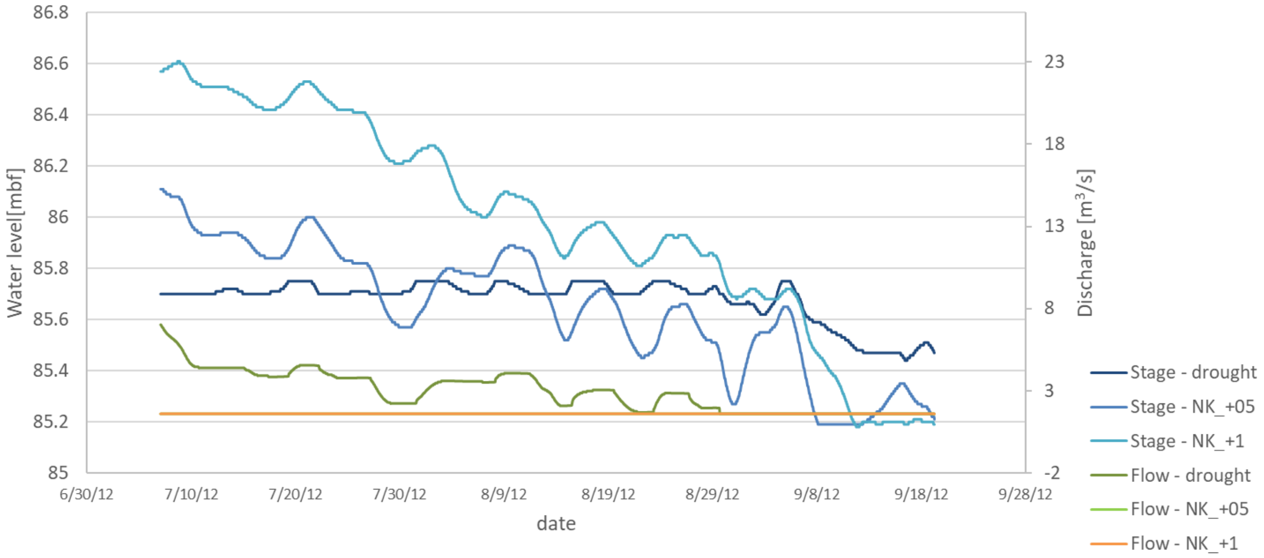

Figure 31. Cross section results end of the West Branch

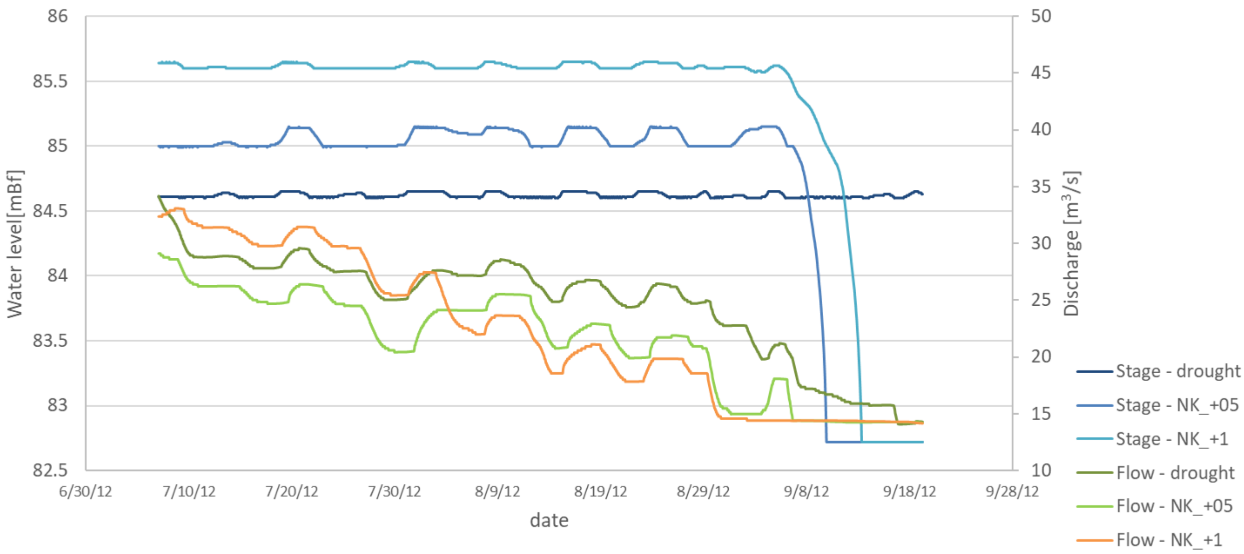

Figure 32 Cross section results end of the East Branch

2.5. Water discharge incrase to retain 0.5 meter higher water level

Related measures:

- D02 Water damming in ditches, wires with constant crest (valleys)
- D03 Active water management on a drainage system (river valleys)

In the second scenario we assessed the effect of increasing the incoming discharge from Lake Tisza.

The modelling work focused on Nagykunsági canal. The analysis was carried out using a real drought situation in Summer 2012.

The modelling work focused on raising of incoming water flow to keep the water level half a meter higher.

During all simulations the operating water level was half a meter higher. The incoming discharge was raised by 5, 10, 15 and 20 m^3/s and analysed the drought situation in Nagykunsági for the future water demands.

The Figures 33., 34. and 35. show the water level and discharge time series at the end sections of Main canal, the west and east branches. Modelled results of the Main canal derive from the upper side of outlet structure. During the simulation we can relese 1.6 m3/s into Hármas-Körös through the Nagykunsági west Branch and 14.4 m3/s to Hortobágy-Berettyó through the East Branch (TIKEVIR regulation).

The Main canal shows that a half meter rise in water level can be realized without incoming flow, and there is additional usable water flow in about 5 m^3/s increase. In the western branch, higher water levels cannot be retained for all simulation time. In the east branch the water level can be retained with 5 m^3/s flow rate and additional usable water flow would be available.

The conclusion is that the increasing inflows provide partly solution.

Legend to Figures 33, 34 and 35:

- NK_+05: the results in Nagykunsági during the drought period with the future water demands (increased water level by half a meter)
- nk_+05_5: the results in Nagykunsági during the drought period with the future water demands (increased water level by half a meter and increased incoming flow by 5 m^3/s)
- nk_+05_10: the results in Nagykunsági during the drought period with the future water demands (increased water level by half a meter and increased incoming flow by 10 m^3/s)
- nk_+05_1_5: the results in Nagykunsági during the drought period with the future water demands (increased water level by half a meter and increased incoming flow by 15 m^3/s)
- nk_+05_20: the results in Nagykunsági during the drought period with the future water demands (increased water level by half a meter and increased incoming flow by 20 m^3/s)

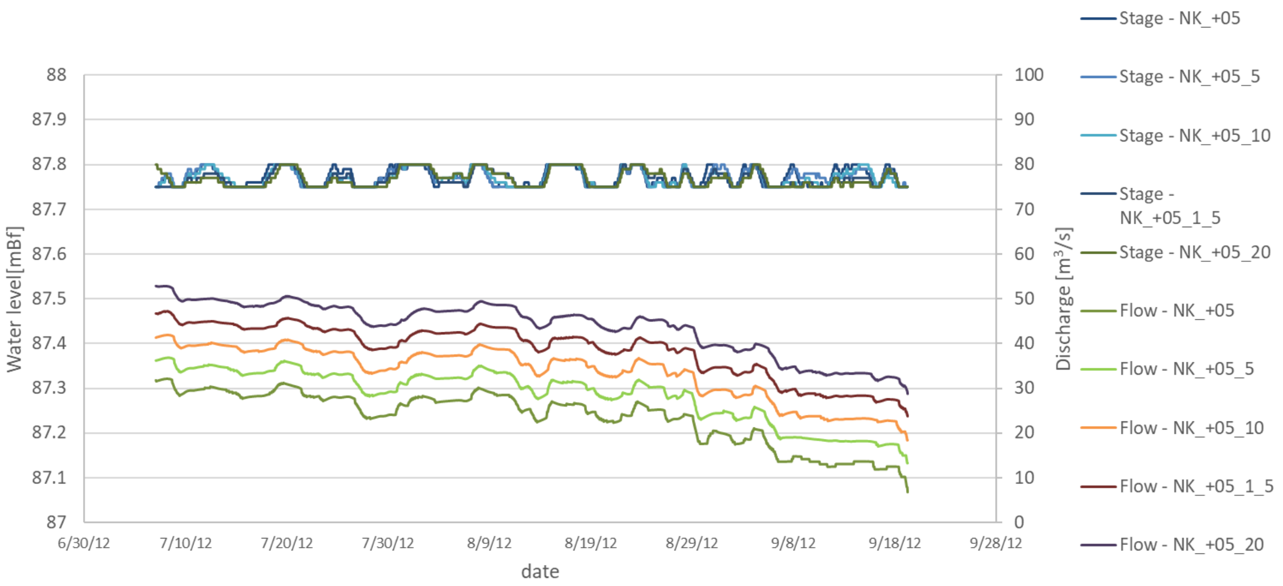

Figure 33. Cross section results Main canal

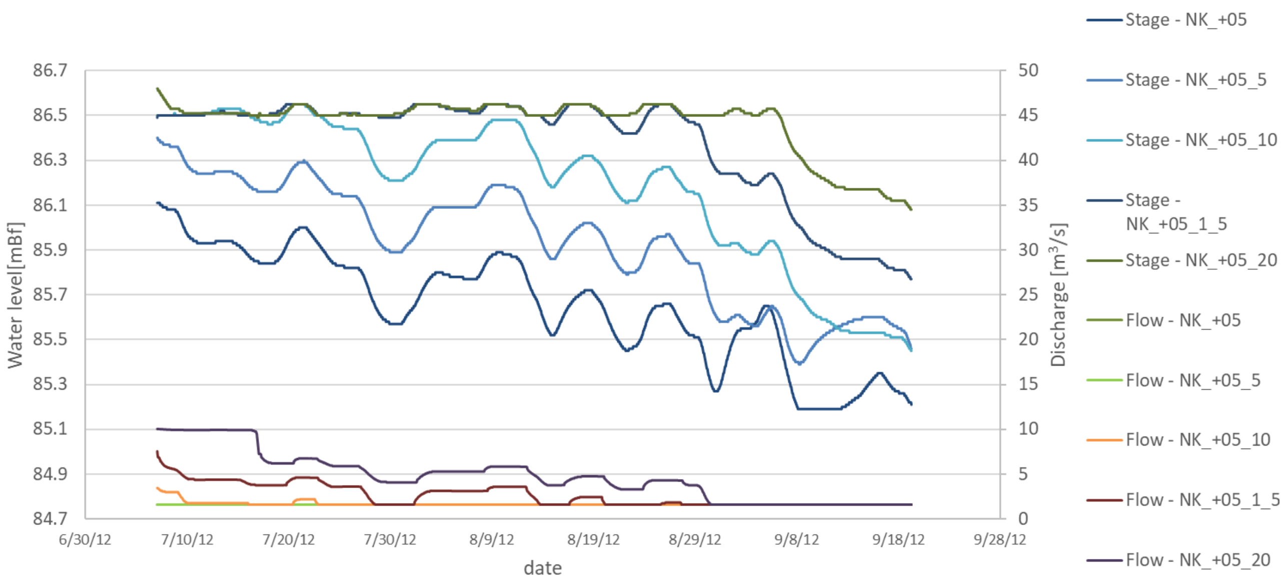

Figure 34. Cross section results end of the West Branch

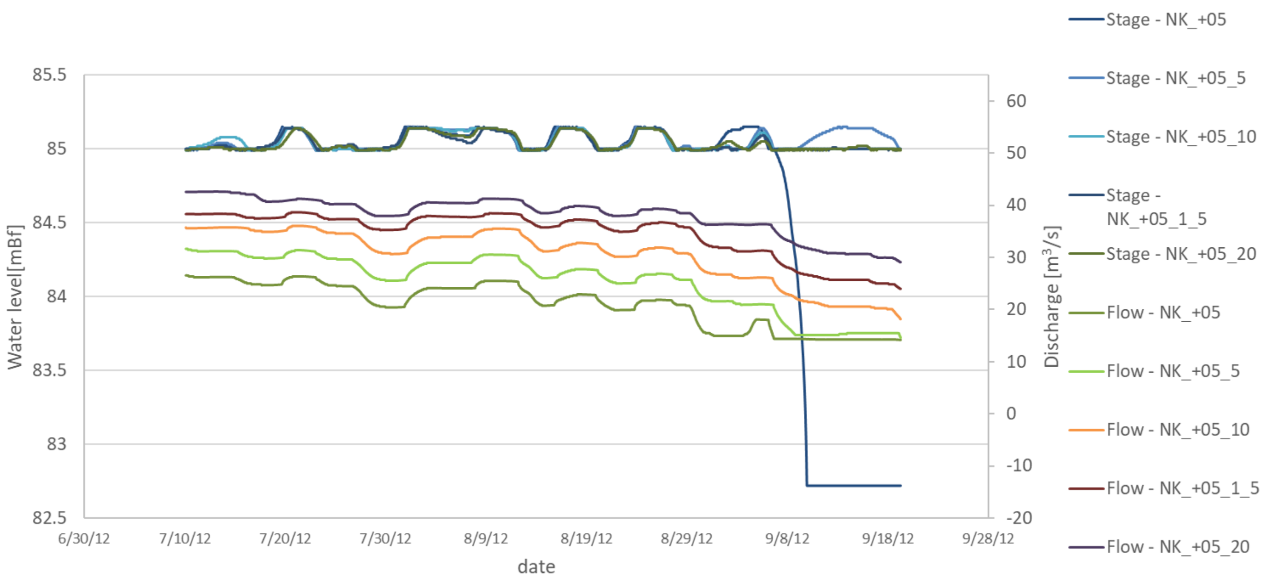

Figure 35. Cross section results end of the East Branch

2.6. Water discharge incrase to retain 1.0 meter higher water level

Related measures:

- D02 Water damming in ditches, wires with constant crest (valleys)
- D03 Active water management on a drainage system (river valleys)

The third examination is further development of version 2: increasing the incoming discharge and reach 1,0 m higher water level.

As previously, the modelling work was carried out using a real drought situation in Summer 2012.

The modelling work focused on raising of incoming water flow to keep the water level one meter higher.

During all simulations the operating water level was one meter higher. We raised the incoming discharge by 5, 10, 15 and 20 m^3/s and analysed the drought situation in Nagykunsági with the future water demands.

The Figures 36., 37. and 38. show the water level and discharge time series for the end sections of the Main canal, the west and east branches. Modelled results of the Main canal derive from upper side of outlet sturcture. During the simulation 1.6 m3/s can be taken into Hármas-Körös through the Nagykunsági West Branch and 14.4 m3/s into Hortobágy-Berettyó through the East Branch (TIKEVIR regulation).

The Main canal shows that one metre rise in water level can be reached with 10 m^3/s incoming flow, and there is already additional usable water flow. In the western branch, higher water levels cannot be retained for all simulation time. In the east branch the water level already can be maintained with 5 m^3/s inflow and additional usable water flow would be available.

The conclusion is that the increasing inflows is partly solution.

Legend to 36, 37 and 38:

- NK_+1: the results in Nagykunsági during the drought period with the future water demands (increased water level by one a meter)
- nk_+1_5: the results in Nagykunsági during the drought period with the future water demands (increased water level by one a meter and increased incoming flow by 5 m^3/s)
- nk_+1_10: the results in Nagykunsági during the drought period with the future water demands (increased water level by one a meter and increased incoming flow by 10 m^3/s)
- nk_+1_1_5: the results in Nagykunsági during the drought period with the future water demands (increased water level by one a meter and increased incoming flow by 15 m^3/s)
- nk_+1_20: the results in Nagykunsági during the drought period with the future water demands (increased water level by one a meter and increased incoming flow by 20 m^3/s)

Figure 36. Cross section results Main canal

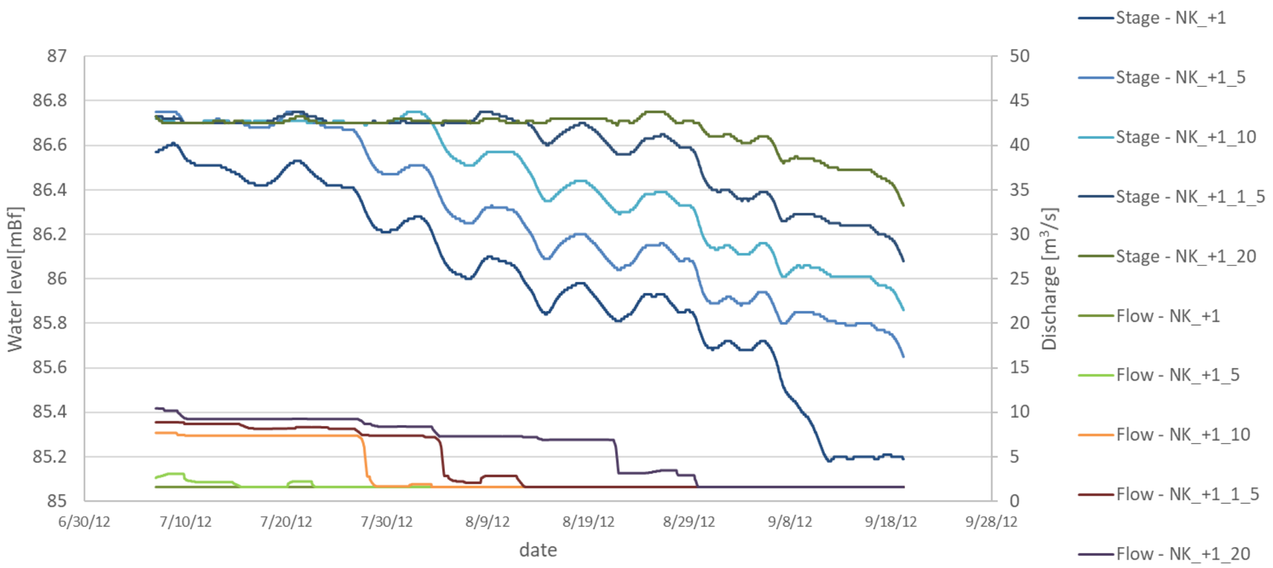

Figure 37. Cross section results end of the West Branch

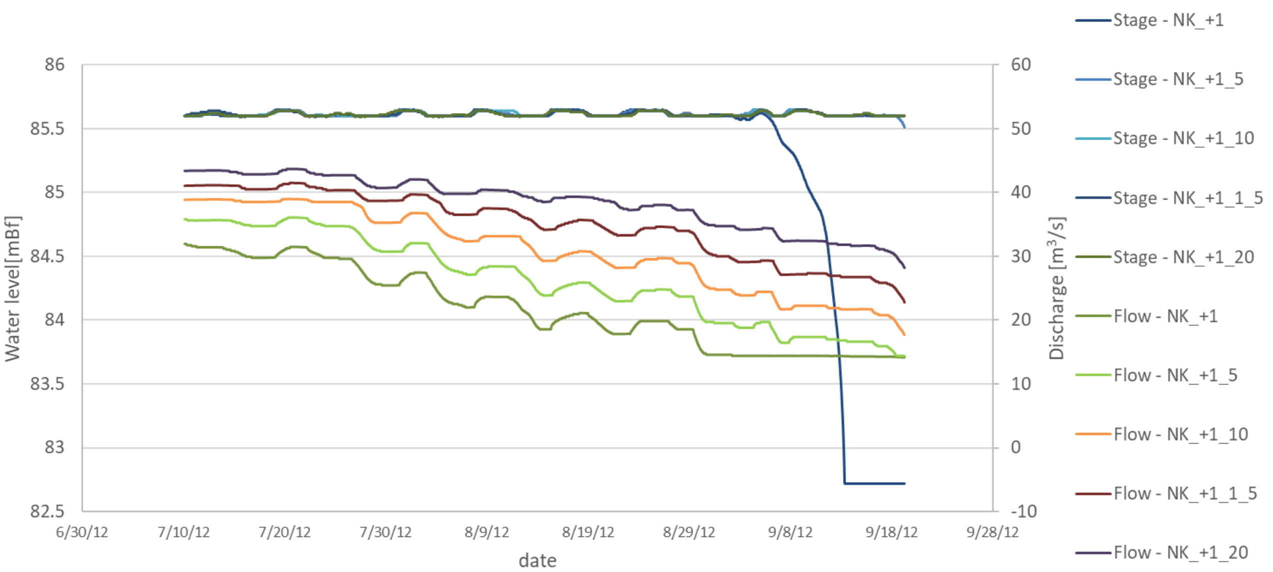

Figure 38. Cross section results end of the East Branch

2.7. Effect of water retention on drought period

Related measures:

- D02 Water damming in ditches, wires with constant crest (valleys)
- D03 Active water management on a drainage system (river valleys)

In this version we assume that the water demand will decrease because of the beneficial effects of the planned measures implemented in the pilot area.

The modelling work focused on Nagykunsági Main canal: the analysis was carried out using a real drought situation in summer 2012. Our modelling question was: what would happen if the water demands decreased.

During the modelling process the assumption was that the irrigation needs decrease because of the retained water in the area (land, drainage canal and oxbows) with the planned measures.

We decreased the water demand by 25, 50, 75 and 100 % and calculated the water levels and discharges in Nagykunsági canal during the drought period.

The Figures 39., 40. and 41. show the water level and discharge time series for the end sections of Main canal, the west and east branch. Modelled results of Main canal derive from upper side of in line structure. During the simulation 1.6 m^3/s can be released into Hármas-Körös through the Nagykunsági west Branch and 14.4 m^3/s into Hortobágy-Berettyó through the East Branch (TIKEVIR regulation).

We can see that with a 25 percent reduction in water demand, additional water is generated for the entire simulation period in all three canal sections. The conclusion is that the decreasing water demand with planned measures is solution to the problem and the system would be sustainable.

Legend to Figures 39, 40 and 41:

- drought: the results in Nagykunsági during the drought period with the water demands
- wd: the results in Nagykunsági during the drought period without the water demands
- wd75: the results in Nagykunsági during the drought period with 25 percent water demands
- wd50: the results in Nagykunsági during the drought period with 50 percent demands
- wd25: the results in Nagykunsági during the drought period with 75 percent demands

It was assumed that the water stays in land, drainage canal and oxbows with the measures we planned, and this causes decreasing irrigation water demand. We calculated 25, 50, 75 and 100 percent decrease of irrigation water demands. We can see on the graphs that the discharges keep growing.

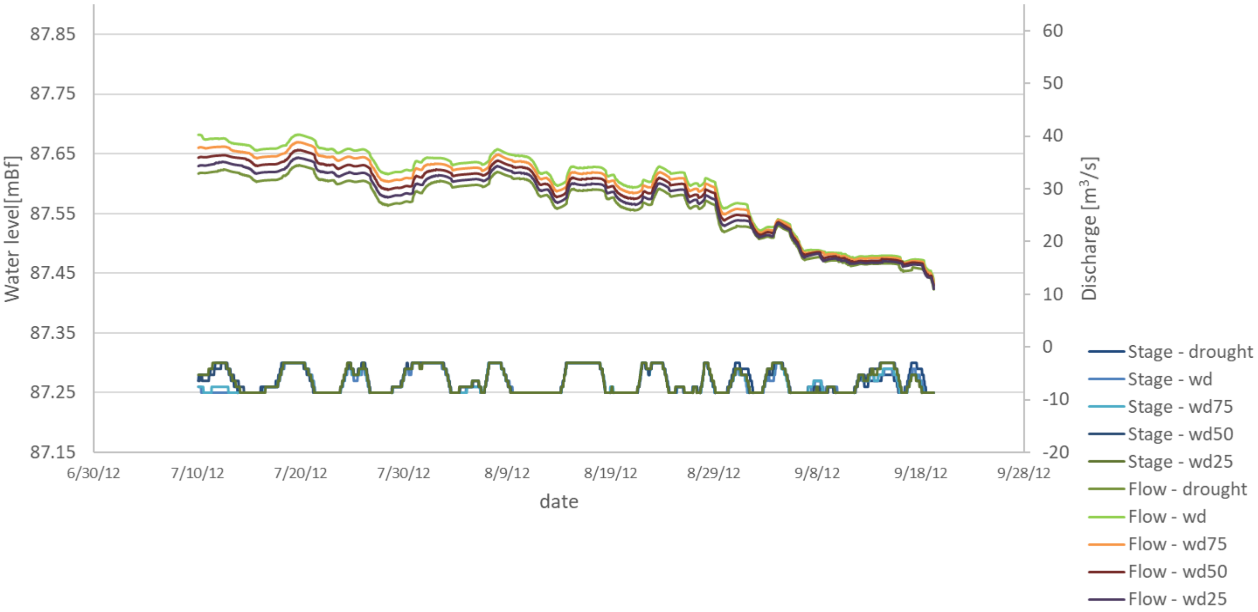

Figure 39. Cross section results Main canal

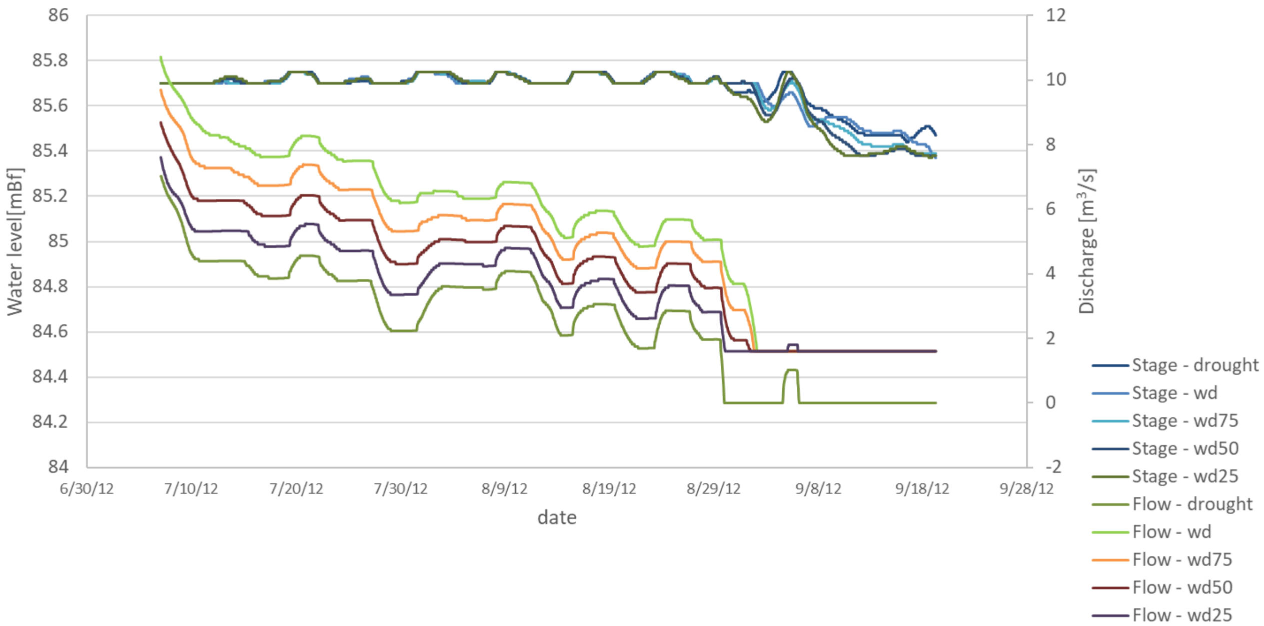

Figure 40. Cross section results end of the West Branch

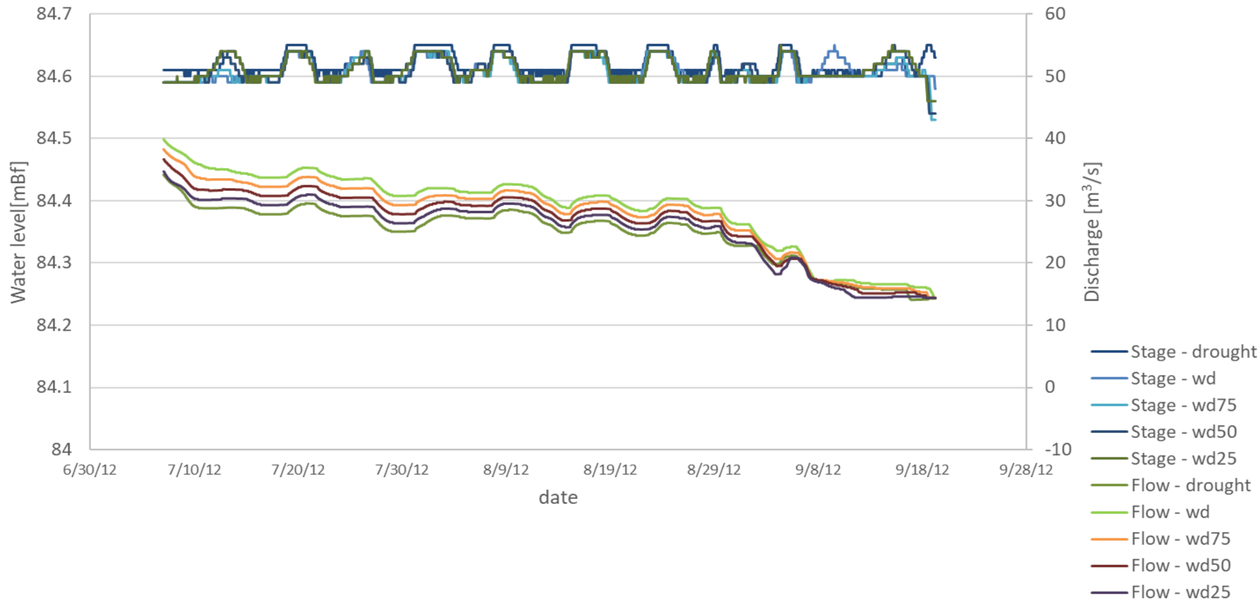

Figure 41. Cross section results end of the East Branch

2.8. Effect of planned water demand on Canals with extra water

Related measures:

- D02 Water damming in ditches, wires with constant crest (valleys)
- D03 Active water management on a drainage system (river valleys)

In the previous results showed that extra water can be generated in Nagykunsági canal with planned measures. It was our idea to bring the extra water to the area classified by FroGis as the worst drought. The planned water transition is shown in Figure 42. We could deliver 1050 l/s water from Nagykunsági to the Harangzugi canal, 200 l/s water to Mezőtúri VI canal and 1000 l/s to Álomzugi canal. So the last two canals would become a dual operation canal.

The modelling work focused on Harangzugi, Mezőtúri VI and Álomzugi canal, the analysis was carried out using only extra water. Our modelling question was whether or not we can serve the future water demand with the extra water.

During the modelling process we subtracted quantity water of the water demands from the extra water.

The Figures 43., 44. and 45. show the discharge longitudinal profile along Harangzugi, Mezőtúri VI and Álomzugi canal. It can be seen that in all three canals the future water demand would be serviceable with the dilution water of Nagykunsági.

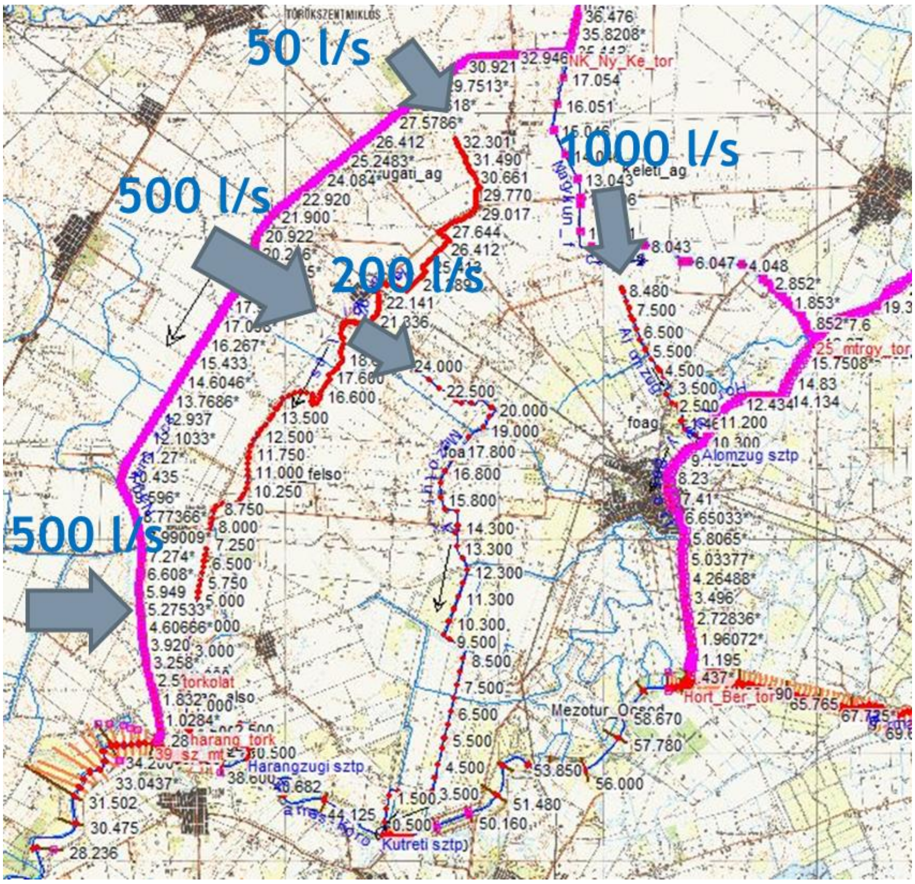

Figure 42. The planned water tranzition

Figure 43. Longitudinal profile in Harangzug

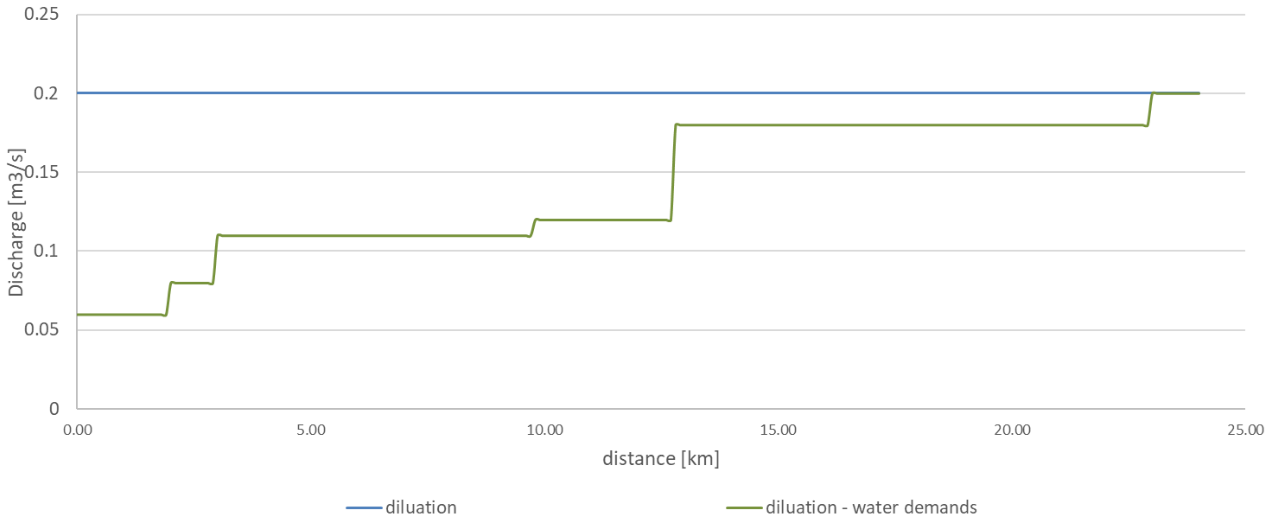

Figure 44. Longitudinal profile in Mezőtúri VI

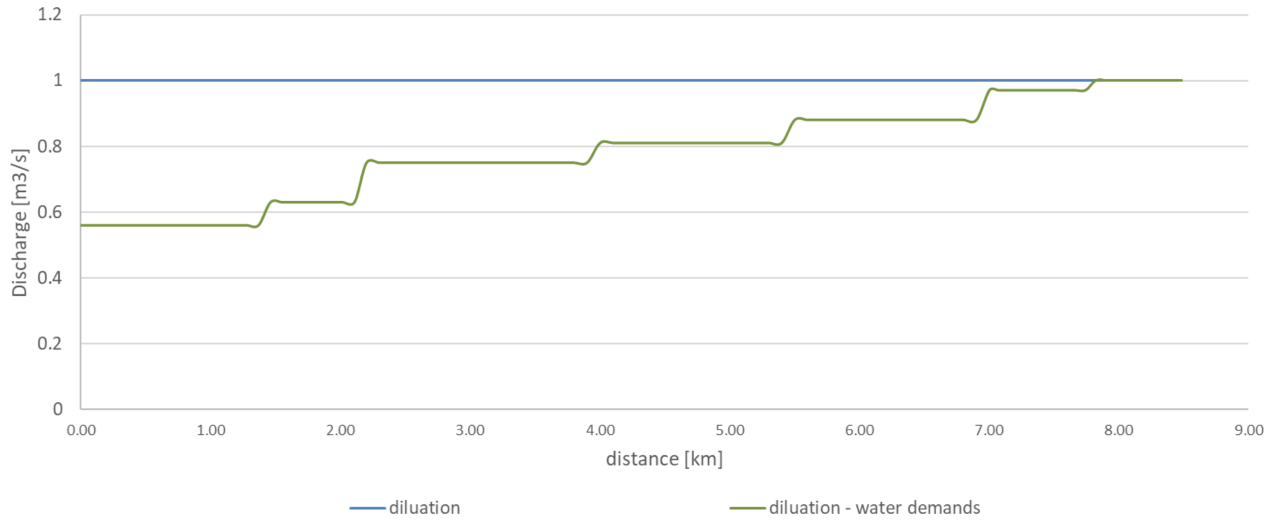

Figure 45. Longitudinal profile in Alomzug

2.9. Impact of excess water retention for dranage canal system

Related measures:

- D02 Water damming in ditches, wires with constant crest (valleys)
- D03 Active water management on a drainage system (river valleys)

During the excess water period, water flows from the fields into the excess water canal and then pumped into the rivers.

The modelling work focused on Harangzugi canal: the analysis was carried out using a real excess water situation from 2015. During the modelling process the assumption was that the water is staying in land with the measures we planned, so less water flow into the watercourse. Our modelling question was that what would happen during the excess water period if the planned measures were implemented.

During the modelling process we subtracted retaining water of the cumulative effects from the excess water.

The Figure 46 show the discharge longitudinal profile along Harangzugi canal. It can be seen that in the Harangzugi final section we reach 300 l/s of water output decrease, which also reduces the pumping activity needs.

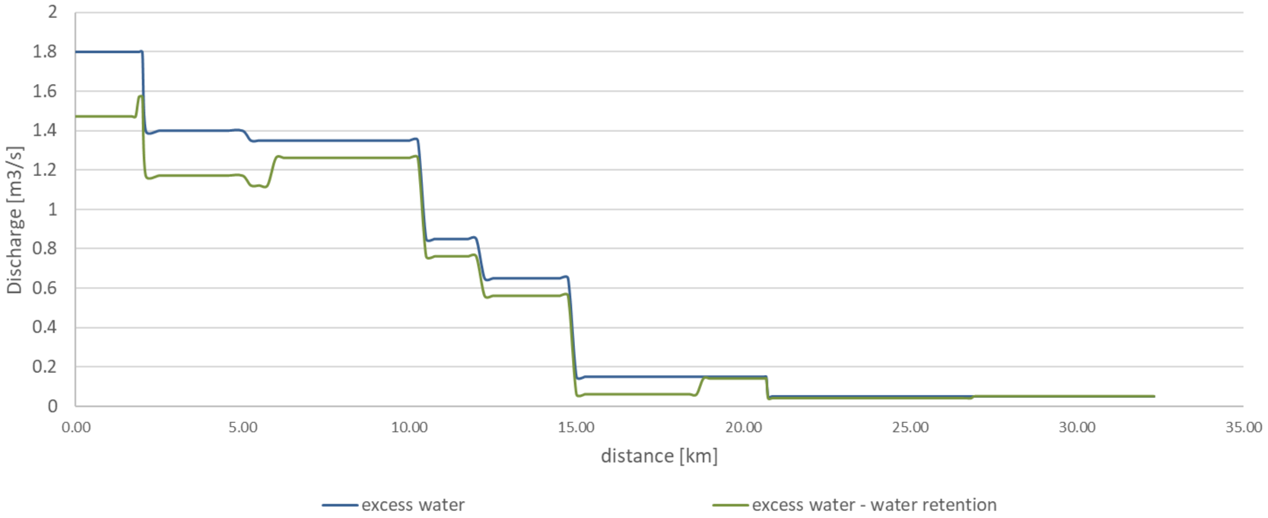

Figure 46. Longitudinal profile in Harangzug

2.10. Effect of diluation water on salt concentration of Harangzugi canal

Water quality is good along the Nagykunsági, because all component group of Water Framework Directive are excellent or good. But the salt component group is only moderate on Harangzugi canal.

Limit values for salt concentration:

- above 1000 mg/l: wrong
- between 500 and 1000 mg/l: moderate
- below 500 mg/l: excellent

The modelling work focused on Harangzugi canal: the analysis was carried out using a real time water situation from 2015. Our modelling question was whether the dilution water improves the classification of the canal.

The Figures 47 and 48 show the salt concentration longitudinal profile along Harangzugi canal without dilution and with diluation in April. The Figures 49 and 50 show the salt concentration longitudinal profile along Harangzugi canal without dilution and with dilution also in April. These months are the critical time periods.

In April, the salt concentration in the lower section of the canal, without dilution, exceeds 1000 mg/l. And with dilution this value is already reduced to between 500 and 600 mg/l. In May, the salt concentration in the lower section of the canal, without dilution, is between 1000 and 800 mg/l. And with dilution this value is already reduced to between 500 and 550 mg/l. The conclusion is that we dilute from Nagykunsági to Harangzugi canal than the salt concentration decrease about half. Dring the irrigation time guaranteed the good quality water supply.

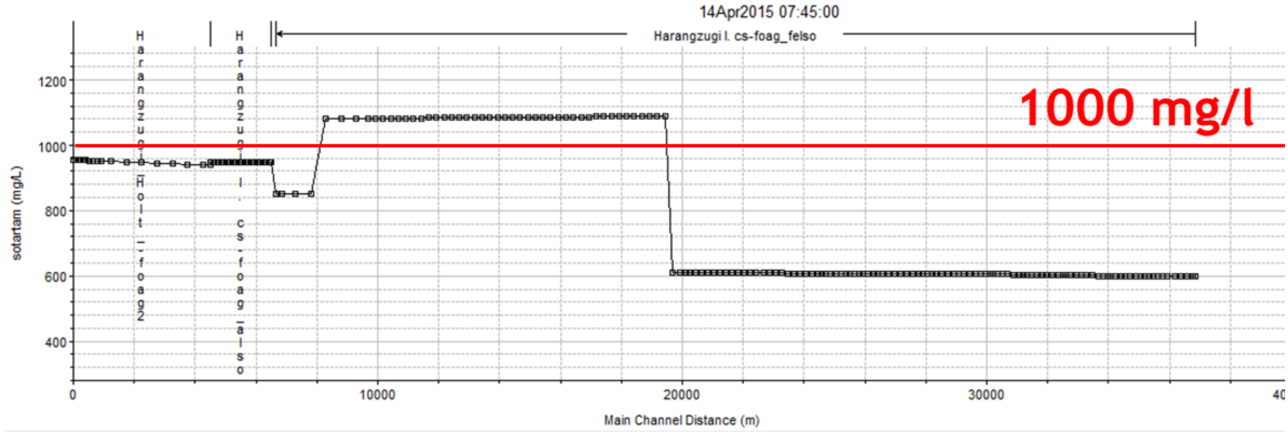

Figure 47. Longitudinal profile of salt concentration without diluation (April 2015)

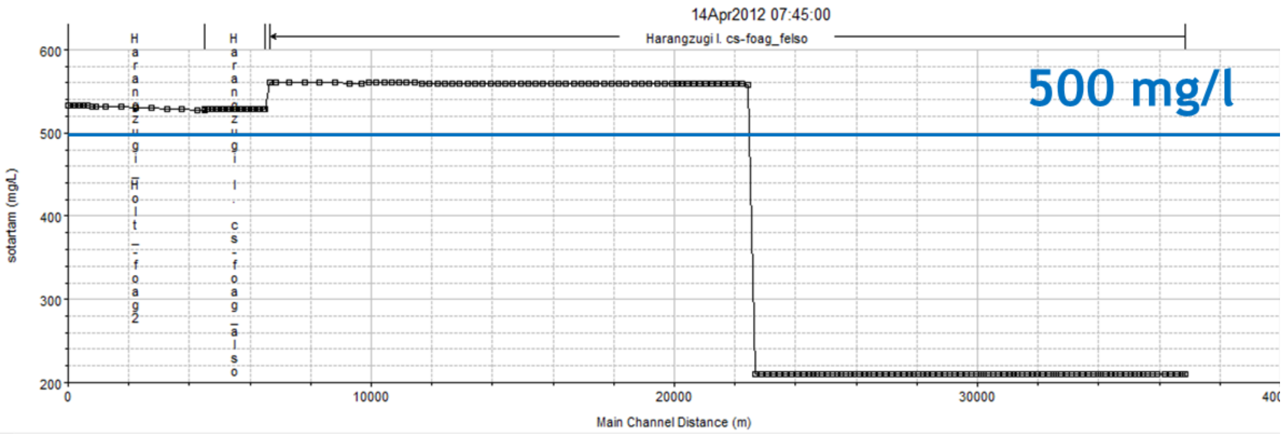

Figure 48. Longitudinal profile of salt concentration with dilution (April 2015)

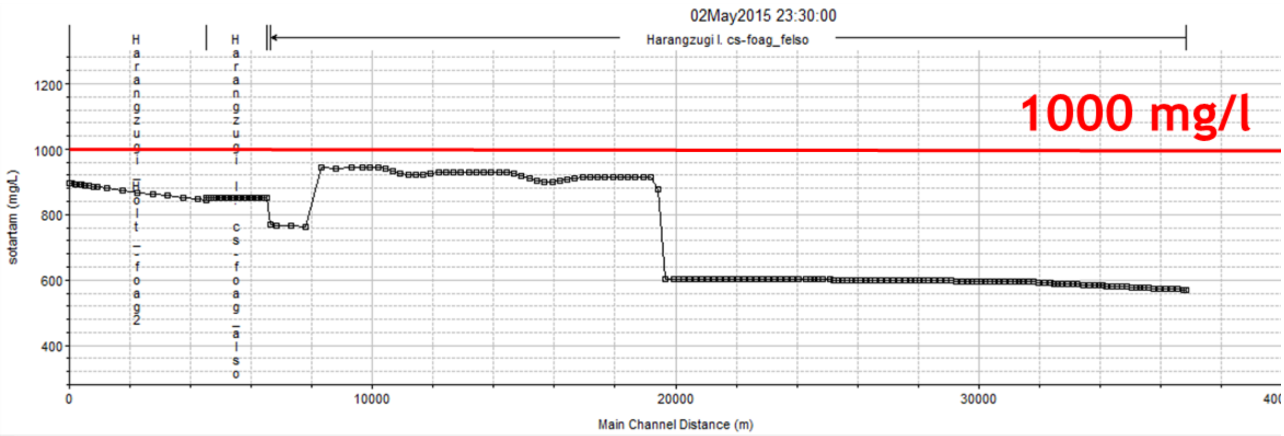

Figure 49. Longitudinal profile of salt concentration without dilution (May 2015)

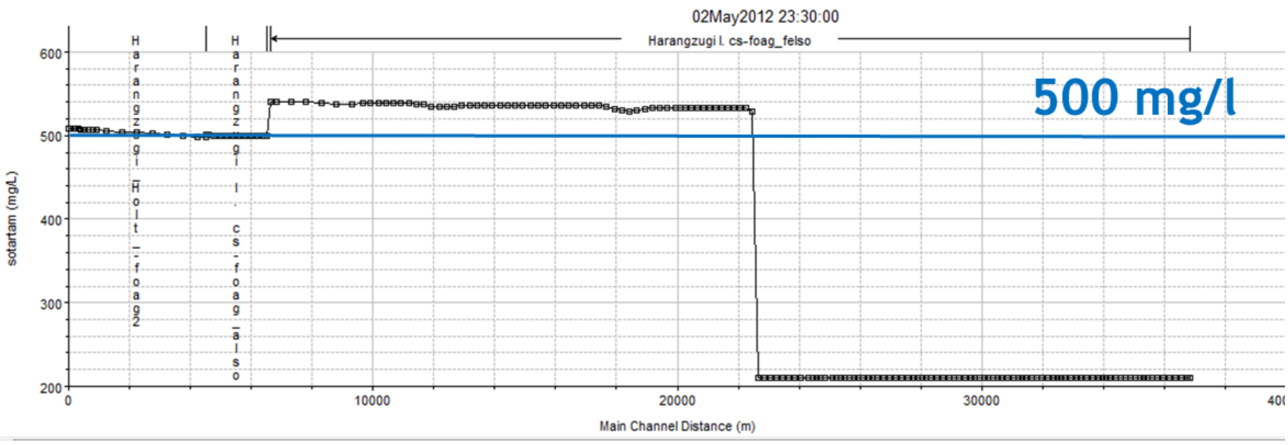

Figure 50. Longitudinal profile of salt concentration with dilution (May 2015)

2.11. Effect of rising groundwater level

The planned measures would increase the amount of stored water not only in the upper layers of the soil but also in the deeper layers of the soil. We assume that the water is staying in the fields with the measures we planned and the groundwater level could improve. We analysed effect of rising groundwater level.

The soil is impermeable in our pilot area and the average leakage coefficient is $8*10^{-5}$ m/day. Furthermore, there are many groundwater wells in our pilot catchment (Fig. 51) and we have water level time series of groundwater well for the year 2012.

During the test, we raised the groundwater level every half meter to three meters but there was not any effects.

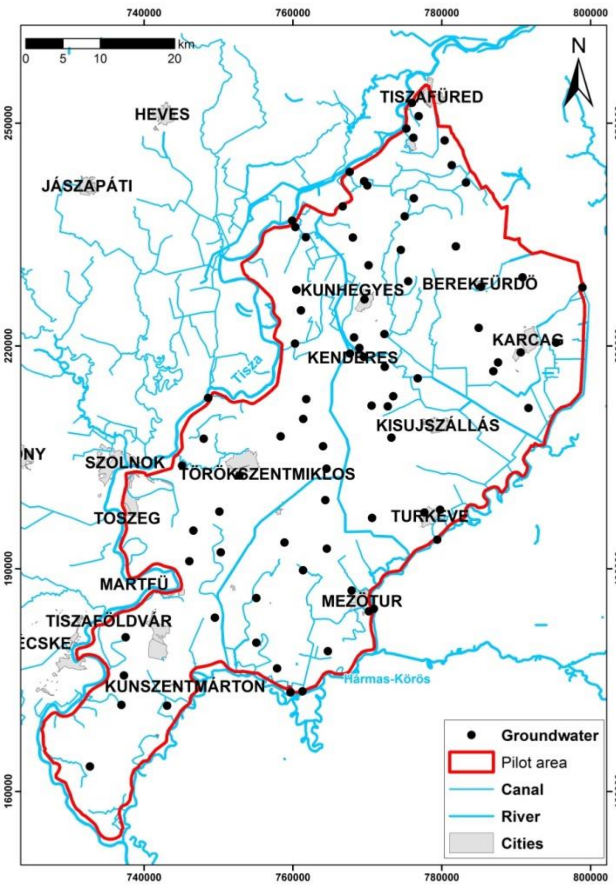

Figure 51. Groundwater well in our pilot area

2.12. Conclusion

We have to see that the 1D hydrodynamic software has limitations. We cannot analyze all planned measures and what we can test also only indirectly. All in all, the water quantitative changes of the planned measures on watercourses can be detected.

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