# 8. Operation of canal systems and multi-purpose water management – Dong-ér catchment

Zsuzsanna Nagy; Gergely Pálfi; Zsuzsanna Priváczkiné Hajdu; Balázs Benyhe

## Introduction

Due to the natural geography of Hungary, nearly a quarter of its territory is a deep-lying flat area, where water cannot be flowed naturally. A significant part of these areas currently concern agricultural land. It is interesting to compare the land use and the extent of the areas currently affected and exposed the excess water with the 19th century pre-flooding management situation. The consequence of continuous anthropogenic effects in the 1940s reached 600,000 hectares of flooded land (Pálfai, 2004), followed by a period of inland drainage. Thus, the size of the areas flooded with excess waters has been reduced in magnitude, but the decline of the “water treatments” previously solved within the field, and in many places due to its almost complete disappearance, the phenomenon has again become significantly visible.

The durability, spatial extent and mass of the inland excess water phenomenon are currently the basis of many land use conflicts related to water management. The question arises as to how long and to what extent a technical solution can be used to respond to the size of the floods (Kozák, 2006) or to find a solution to the situation elsewhere.

The present document seeks to discuss the principles and thoughts leading to the answer to this question, from several sides.

## Genetics and measurement of excess water

Classes of inland excess water can be differentiated based on the Hungarian literature (Török 1997, Pálfai 2001; Pásztor et al. 2006; Kozák 2003, 2006; Barta et al 2013). What is common in all types of inland excess water cause local depressions to be filled with water which can vanish depending on the meteorological conditions, soil characteristics and human intervention. The types are following:

- Horizontal or accumulative type of inland excess water – usually originates from precipitation, but topography and soil factors can also have considerable effect (Rakonczai et al. 2014a; Benyhe 2013, 2015; Barta et al. 2016).
- Vertical inland excess or upwelling inland excess water or "Earth flood" – when the ground water table arises higher than the surface.
- Queuing up or Vágás-type of inland excess water. This inundation type occurs usually at the locations of pump stations or at dams because of the failure or insufficient capacity of the channels or pumps.

The following general approaches are usually applied to study inland excess water in the Hungarian Great Plain:

- Description of observed extent of inland excess water. Mainly based on survey visits and perception maps, photography, aerial photography, etc. (Licskó et al., 1987; Rakonczai et al., 2001; van Leeuwen et al., 2017).
- Vulnerability maps which mainly based on GIS, considering topographical, soil and land use factors (Pálfai, 2004; Pásztor et al., 2014; Bozán et al., 2018). Their scale is usually regional or national level
- Remote sensing techniques which are using high resolution remotely sensed data such as spectral and hyperspectral images, radar data, satellite information, etc. (Csornai et al., 2000; Rakonczai et al., 2001; Mucsi and Henits, 2010, Csendes and Mucsi, 2016). This method is suitable for classifying inland excess water (LEEUWEN et al., 2013)
- Complex physically distributed models to simulate the hydrological processes causing inland excess water (Kozma, 2013, Leeuwen et al. 2016).

## Model area

The area of interest, is the Dong-ér catchment situated on the Danube-Tisza interfluve and partly on the Lower-Tisza valley (Fig. 8.1/a.). The main watercourse is the Dong-ér canal which is transports the waters towards the Tisza River as the final recipient. The basin can be divided into two parts, the elevated sandy ridge region and the former floodplain zone along the river Tisza.

The area's surface is mostly determined by changes in the Quaternary. Fluvial (Danube) and eolic surface shaping were dominant. Wind-blown sand formation continues in accordance with the prevailing wind direction, NW and as a result covers the former loess or wind-blown sand areas. Along the Tisza Valley chernozem soils become dominant over fine sand loess layers.

The climate of the model area is moderate or warm-dry. The average annual temperature fluctuates between 10.2 and 10.7 °C. The annual rainfall ranges from 520 to 570 mm, but in extreme cases, it is less than 400 mm. On the basis of the droughts that have occurred so far according to Pálfai's classification, it belongs to the heavily droughty, very strongly droughty zone.

The Dong-ér system can be described as two main sub-systems; (1) Dongér-Kecskemét (905 $km^2$), and Dongér-Halasi inland excess water system (1011 $km^2$). The use of surface waters in the area is low due to the sparse rainfall and runoff, so the use of the underground stocks is mostly dominant. The vertical lower boundary of the water reservoirs can be drawn at the first water-permeable layer from the surface at an average depth of 20-30 m. Based on the available agrotopographic map the area is heterogeneous. The most dominant soil types are sandy soils, humus sands, windblown sand, chernozem and salt-affected soils (Fig 8.1/b). Due to heterogeneous terrain and soil conditions, and the highly artificial drainage network, the excess waters can lead to various and unpredictable processes.

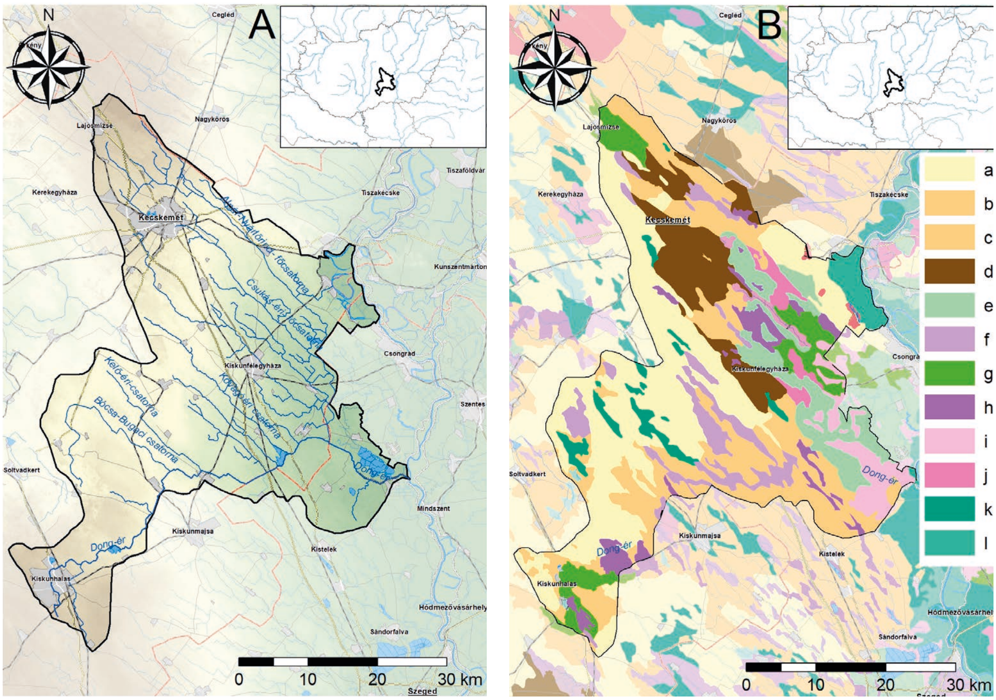


Figure 8.1 *Topographic conditions and canal network of the Dong-ér catchment (A) and soil types of the area (B) a: blown sand, b: humic sandy soil, c:chernozem-type sandy soil, d: lowland chernozem, e: meadow chernozem, f:solonetzik meadow soil, g: meadow chernozem with salt accumulation in lower layer, h: solonchak-solonetz, i: meadow solonetz, j: meadow soil, k: meadow alluvial soil, l: steppe-meadow solonetz*

## Analyses of excess water development

### Flooding analysis – Endorheic basin analysis

In this preliminary analysis, flood-prone areas were identified with GIS techniques based on digital elevation model focusing on depressions or areas which doesn't have outlet flow. The expected results of the analyses are flood maps with the extent of flooded area, water depth, volume of the water stored in the depression and flow path network. The model results depend only on the terrain model and other factors are not taken into account, the calculated flood areas  are expected when the water can move freely on the surface, it doesn't infiltrate to the ground, nor does the surface cover prevent its' flow. In reality, similar conditions occur with saturated or possibly frozen soil conditions, especially during winter.

Analyses were made for 10, 30, 60, and 100 mm precipitation height. Flooded areas are shown in the attached maps, furthermore their areas and volumes can be seen in the table below. Lakes with more or less permanent water-cover have appeared on the resulted maps as inundation, but their areas and volumes had been subtracted from the summarization.

This preliminary analysis could give useful information during the calibration procedure of the surface runoff models.

### MIKE SHE analysis – accumulation of excess water

Modelling of excess water is a challenging and complex process. For the sufficient representation of the hydrological processes, the applied model has to deal with the followings: (1) precipitation, (2) run-off, (3) evaporation, (4) evapotranspiration, (5) infiltration, (6) water movements in saturated and unsaturated zone, (7) water movement in the channels and (8) storing water on the surface. It is important that these processes are interconnected and affecting each-other. In addition, the operational activities must also have to consider several point of views during intervention, therefore an integrated approach of the problem must be evaluated. Fulfilling this criteria, the MIKE SHE integrated catchment modelling software was chosen, offering high quality and fast solutions for complex water movement and accumulation processes.

The aim of the MIKE SHE analyses is to develop a calibrated model what is suitable to satisfy the needs of operational planning and decision making during extreme hydrologic conditions.

As first step after all of the input data evaluation and pre-processing to initialize main calibration parameters. In case of Dong-ér catchment, several necessary inputs were missing, so we concentrated for that timeframe when measured data were available. 2015 and 2018 springtime were selected because for that timeframe were available flood extent maps and underground water-levels.

## Results

### Excess water inundation extents and volumes

The results of the analysis determine the extent and volume of endorheic basins. A comparison validation was taken by using existing excess water inundation maps, marking the locations of the regularly flooded areas (Fig. 8.2). It was revealed during the validation, that no significant flooded areas exist on the upstream part of the catchment regardless the topography showed certain areas without outlet. It has to be considered, that infiltration and subsurface water movement has a major importance in the sand ridge region and the effect of topographic conditions is only secondary.

It is also notable that most of the possible inundation locations appear in a certain distance from any canals, however the experience shows that runoff can be blocked by the deposited material of the canals (Kiss and Benyhe 2015). Unfortunately this effect could not be identified on the results, due to the poor quality if the terrain model.

Assuming saturated soil conditions, when no infiltration can occur, a normal rainfall event can already accumulate in approximately 183 km$^2$ (9,5%) of inundation in the catchment area, based on the simulation results. Considering higher rainfall, it is noticeable, that even a 100 mm rainfall event will result only in a 360 km$^2$ of total inundation, that is 18% of the catchment area (Fig. 8.3). The relationship between volumes and precipitation is even lower, because no additional water can be retained in the endorheic basins, highlighting the limitation of available storage areas.

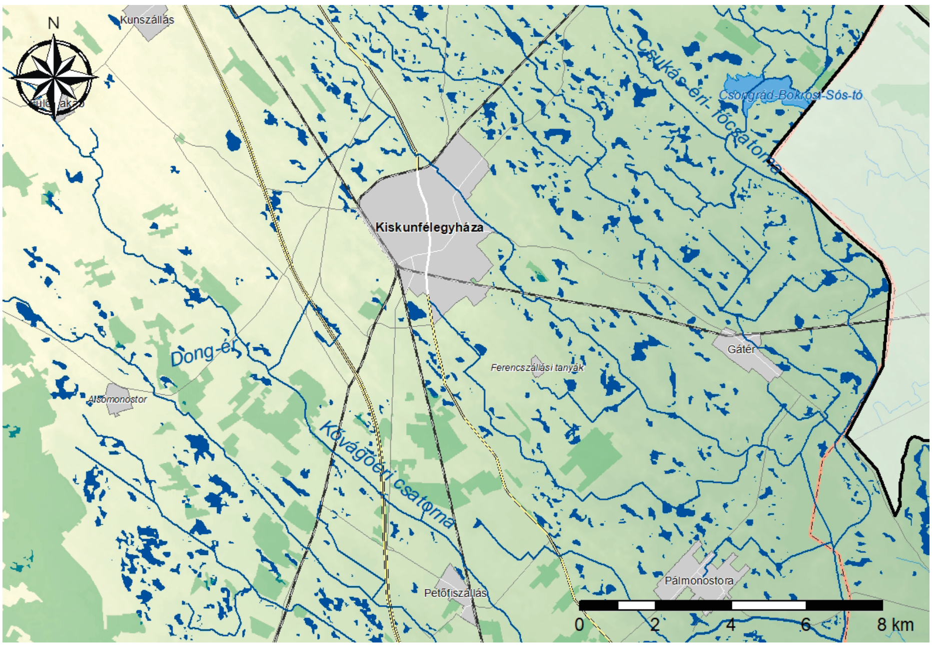


Figure 8.2 *Location of inundated endorheic basins with a 30 mm rainfall simulated*

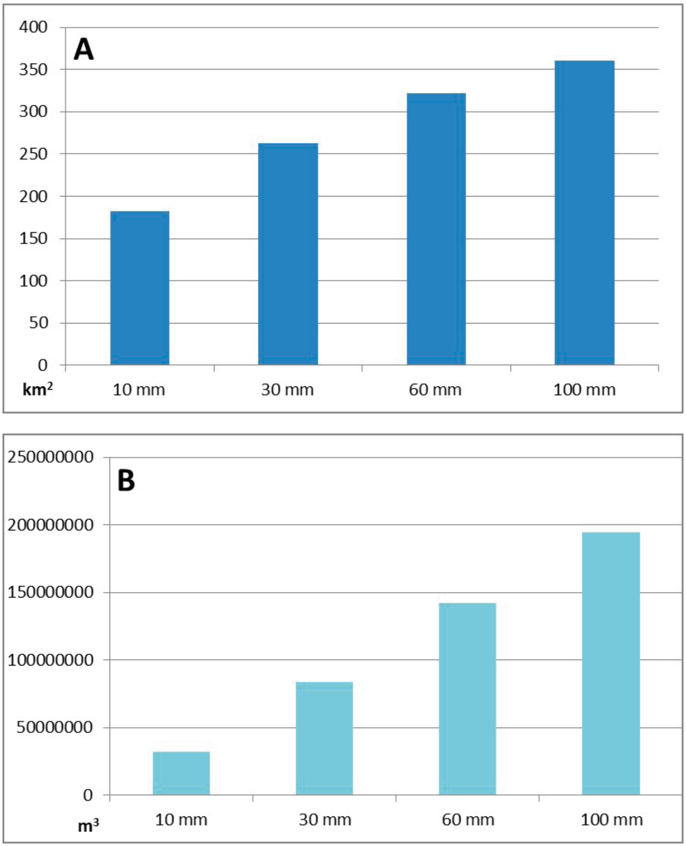


Figure 8.3 *Area (A) and volume (B) of total inundations in the Dong-ér catchment resulted from endorheic basin analysis for different rainfall amounts*

## Integrated hydrologic model of the Dong-ér catchment

The purpose of the developed MIKE SHE model was to support the operational procedures in relation with excess water management, water storage, structure control, canal maintenance and other water resource management procedure in the Dong-ér excess water system. As the hydrological processes are in connection making a complex system, the experts can take the advantage of the model, which is capable to integrate all the relevant phenomena, and dynamically follow the changes in the water balance of the canals and the watershed.

Due to limited hardware availability, the entire modelling timeframe (2010-2018) had to be cut, therefore shorter periods could have been evaluated. It is seen in the example of 2018, that the model had resulted significant inundation areas in the eastern part of the catchment area (Fig. 8.4). The modelled excess water inundation patches were validated with available inundation maps created by the colleagues of the University of Szeged.

It is visible that the model overestimated the number and size of inundation patches. Approximately 132 km$^2$ of excess water inundation appears on the derived map, but the validation showed that only a small portion was covered by water that time (2018.03.25. – 2018.04.01.). The resulted inundation map shows large excess water patches along the drainage canals, suggesting the "Vágás-type" inundation development process. As a result of canal capacity deficiencies, the downstream areas of the catchment can be endangered by surplus water coming from upstream, inundating the bordering areas if the water level emerges above the elevation of the canal banks.

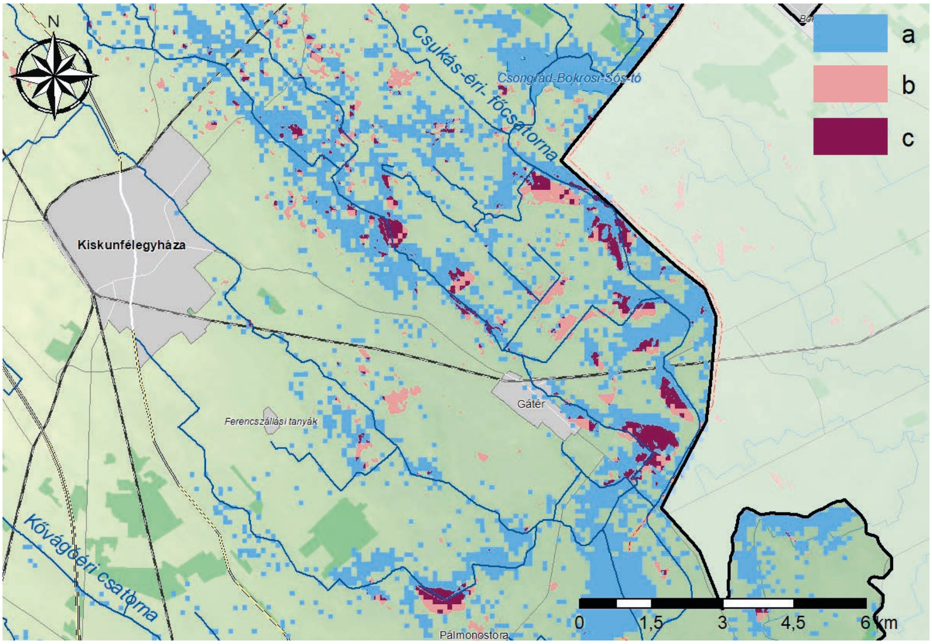


Figure 8.4 *Inundation areas derived by MIKE SHE model (a), compared with areas derived from excess water map of SZTE (b) and validated inundation patches (c)*

Since there is no continuous monitoring along the canals in the Dong-ér catchment, the calibration of surface water flows was not possible for recent situations. Operational water level and discharge measurements occur during excess water protection periods, however these data are only momentary, which cannot be compared with model results that are fluctuating due to the numerical instabilities.

Despite all of this, the subsurface water levels and gradients could be calibrated with existing control monitoring wells' time series. The modelled groundwater levels were promisingly giving back the observed control values, and the average error of the head elevation of the saturated zone was below 0,5 m, which is a remarkable result, considering the poor quality and quantity of input subsurface input data. As the subsurface water balance somehow correlates with the calibration values, it can be supposed that the overestimation of the modelled inundation area is possibly related to the inaccurate evapotranspiration estimations. Unfortunately evapotranspiration itself is based on certain factors (such as land use, crop type, soil structure etc.), that does not have sufficient calibration possibilities.

The head level of the calculated groundwater table is strongly following the topography (Fig. 8.5), with a well-defined gradient towards the Tisza valley. The head elevation values are calculated for each time step, granting the user with current water storage amounts and subsurface flow rates as well. As the underwater fluxes are having significant effect charging the drainage canals and emerging above the surface of depressions, these model results can be evaluated both for mapping and for capacity and water resource analyses.

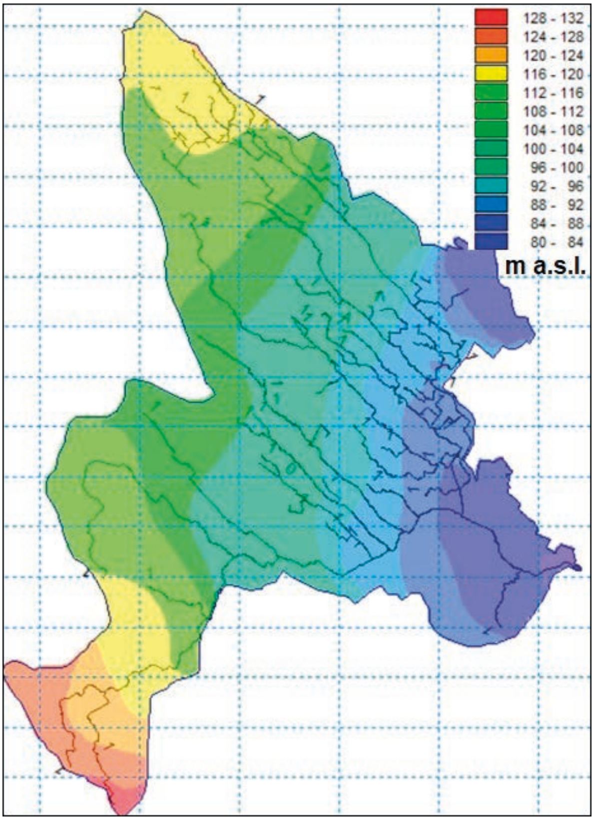


Figure 8.5 *Map of calculated head elevation in saturated zone*

## Discussion of modelling results

Due to the missing or not up-to-date input data, MIKE SHE model results can – and must – be improved. Otherwise on the reached level of calibration, modelling approach is showing the potential of it. As MIKE SHE uses detailed physical based methods, all important phenomena can be modelled and quantitatively calculated. MIKE SHE can be a useful tool to simulate accumulation of excess water in the past, extend the measured data for the catchment and use it as tool for evaluate different type of measurement in the field (e.g.: land use change, new channel designs, etc.)

As no surface monitoring station could be used for surface water flow validation, the model still need to be updated with input data both for calibration and validation procedures. This insufficiency will be handled by the operation of two new discharge monitoring stations being built in the downstream and middle part of the Dong-ér canal. These equipments will provide essential information about water level and discharge values to the water management service.

There are other crucial input parameters that must be improved to develop an accurate excess water model. These are mostly the topography and vegetation cover maps, that unfortunately being updated sparsely, but there were some quality issues with control structure database also which must be upgraded by the water management service. Besides the insufficient temporal distribution, the available values can also be questioned and mostly these parameters (such as LAI, root depth, hydraulic conductivity values) cannot be validated, therefore they will be contributed as calibration values.

In case of examination excess water phenomenon main calibration measured data are obligatory. Beyond that there are lot of uncertainty in many parameters to make the calibration process hard, still the hardware and human resource availability is one of the greatest challenges. Physical based modelling is a good tool to select the most sensible parameters, aiding different sectors of water management to focus to the most important scientific and operational developments.

## Water control programme

The objective of the water control programme is to survey the water control situation of the area – which was processed within the framework of the Water at Risk project utilising a complex water resource management numerical model – and to make suggestions to apply the model and its results to daily operational water control practices.

### Factors influencing inland excess water accumulation and drainage

The surface is dissected, due to deflation and gradient conditions valleys that are parallel to each other runs along the catchment with NW-SE direction. Inland excess water drainage and control structures were mostly built in the bottom of these valleys, but undrained depressions can be also found over the ridges.

Natural gradient conditions make the drainage of large quantities of water possible. It works against these technical opportunities that the waste water from nearby towns and villages often go into these canals too, therefore the rapidly growing plants, organic matter and sludge deposited result in the reduction of the water carrying capacity of the canals.

There are many infertile patches of land called *semlyék*. In the southern part of the inland excess water system, in the Kővágóér, Galambosér and Szentkútér inlets so-called meadow limestone has been formed, which can be 20-30 cm thick at certain places. At some parts this layer cuts into the canal section, by this obstructing the construction of the earth bed and structures of the canals. Under the limestone usually there is running sand that is under artesian water pressure, and the limestone layer that is present in certain parts and the groundwater below it that is under pressure can constitute an inland excess water increasing factor.

The section of the Dong-ér-Halas inland excess water system No.34 that is situated along river Tisza is mostly deep-lying floodplain. It is characteristic of its topography that it is divided by old riverbeds with an average gradient of 1 m/km.

Approximately 50% of the land is agricultural land and the proportion of meadows and grazing land is 30%. There are large parts that classify as nature conservation area, which can influence the water drainage rate. The size of protected areas is 55,614 ha, the size of Ex lege protected land is 530.6 ha.

## Technical and demographic characteristics of the inland excess water systems discussed

### Installed discharge intensity of canals

In the Csukás-ér catchment it is 21.35 l/s/km$^2$, in the Alpár-Nyárlőrinc main canal catchment the installed specific water flow is 23.25 l/s/km$^2$, calculated without storage. In the Dong-ér inlet the installed discharge intensity is as follows: Dong-ér inlet: 16.7 l/s/km$^2$, Büdösszék inlet: 9.6 l/s/km$^2$, Bócsa-Bugac inlet: 8.4 l/s/km$^2$, Tázlár inlet: 41.9 l/s/km$^2$, Alsószállás inlet: 43.1 l/s/km$^2$. The installed discharge intensity of the Dong-ér inland excess water system No.34 is 18.6 l/s/km$^2$.

### Inland excess water hazard index and inundation data

Due to the area's geographical characteristics the inland excess water hazard is present in the deep-lying floodplains. Based on the inland excess water hazard index (Pálfai), more than half of the area is at risk (Table 8.1). The biggest inundations registered in the inland excess water system in the 1966-2018 period affected 50,000-87,000 ha in the inlet No.33 and 6,500-7,500 ha in the inlet No.34. In the other inland excess water periods the average size of inundations was between 3,000 and 5,000 ha (Table 8.2).

Table 8.1 *Distribution of inland excess water hazard in the Dong-ér catchment*

| Palfai IEW Vulnerability | area [km$^2$] | proportion [%] |
|---|---|---|
| no vulnerability | 715,3 | 36,2 |
| moderately vulnerability | 1082,8 | 54,8 |
| medium vulnerability | 146,2 | 7,4 |
| high vulnerability | 31,6 | 1,6 |

Table 8.2 *Size of inundated areas in the Dong-ér catchment*

| Period (year) | 33. sz. Dongér-Kecskeméti | 34. sz. Dongér-Halasi and 36. sz. Percsora-Sövényházi |
|---|---|---|
| | Inundated area (ha) | Inundated area (ha) |
| 1966 | 87000 | 3933 |
| 1970 | 50000 | n.a. |
| 1975 | 72000 | 4089 |
| 1999 | n.a. | 6900 |
| 2000 | 4600 | 6500 |
| 2006 | n.a. | 3550 |
| 2010 | 3450 | 7500 |
| 2011 | 3650 | 7500 |
| 2013 | n.a. | 4400 |
| 2014 | 1550 | n.a. |
| 2015 | 2500 | 5100 |
| 2016 | 1950 | 2250 |
| 2018 | 3050 | n.a. |

### Demographics

In the Dong-ér-Kecskemét No.33 and the Dong-ér-Halas No.34 inland excess water systems there are 21 towns and villages, the total population of these is 210,000. From this population 53%a live in Kecskemét.

## Priorities and related legislation in water drainage and inland excess water protection

In today's legislative environment there are 3 fundamental laws governing protective operations against water damage:

- Act LVII of 1995 on *Water Management*
- Government Decree 232/1996. (XII. 26.) on *Rules of protection against damages caused by flood*

- KHVM Decree 10/1997. (VII.17.) on *Flood and inland excess water protection*
- Act CXXVIII of 2011 on Disaster Management and amending certain related acts

The water management act regulates the water management tasks of the state and municipalities in detail, and also the tasks of land owners, therefore flood protection and inland excess water protection related tasks too. Furthermore, the law regulates water damage protection activities, their organisation, control, supervision and tasks beyond the scope of local general interest tasks performed with the objective of protection against damages caused by water.

Implementation of measures against flood protection is governed by Government Decree 232/1996. and KVMH Decree 10/1997., as regards the criteria for ordering inland excess water state of alert, the steps to be taken at the different stages, the tasks and scopes of authorities of the personnel doing the protection work, the contents of protection plans, plus the rules and procedures of drainage, inland excess water storage and water retentions.

In Hungary water management and water damage prevention, including the protection against inland excess water, is controlled by the state. The main supervisor of this work is the minister responsible for water management. Protection tasks – building the defence structures, improving and maintaining them, protective measures – these are the shared obligations of the state, the municipalities and other stakeholders. State tasks related to flood damage prevention are performed by the water management directorates. It is the directorates' job to harmonise the maintenance, operation, reconstruction and development work related to the built water control structures owned by the state, the municipalities and land owners.

Since 2012 it has been the Ministry of Interior's[1] responsibility to control water management affairs, this field belongs to the deputy state secretariat for public work and water management. The operative tasks of the state are performed by the General Directorate of Water Management (OVF). The minister and the government establish a National Technical Operative Unit (OMIT) for the nationwide management of technical tasks related to flood and inland excess water protection, and they control the process via this unit (Priváczkiné and Muhoray 2018.).

In case of emergency, the rules laid down in the act on disaster management[2] must be followed. If there is an extreme inland excess water situation, the state of emergency is ordered by the director of water management via the OMIT or by the mayor and the engineers of HVB and MVB[3] via the BM OKF[4] (Priváczkiné et al. 2019.).

1 Since 1953 water resources management has belonged to several ministries and underwent numerous restructurings. Discussing this can't be the subject of this chapter due to length limitations.
2 Act CXXVIII. of 2011 on Disaster Management and the amendments of related acts, amended in 2012.
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## Water control in practice, as stipulated by the laws in force and the rules of operation

The surface of the sample area's inland excess water system is mostly plateau type; as for its topography, it is primarily defined by its location on the sand ridge in the Danube-Tisza interfluve. It slopes towards the South East, in the direction of the river Tisza's deep-lying floodplain and towards the Tisza-valley. Thanks to the sloping characteristics, the waters of the inland excess water system can be gravity drained with the canals constructed in the North West – South East direction into the recipients and main recipients.

With the help of weir structures, the discharge of inland excess water can be regulated. Water retention must be performed by means of designated reservoirs, temporary reservoirs, and agricultural land representing lower value, with the exception of the situation when considerably value is in danger.

The main recipient of inland excess water system is the Dong-ér main canal, which carries the collected water into the river Tisza. Gravity discharge only ceases to exist when there is an extreme (standard) flood wave on the river Tisza. When this situation occurs, the received water can be carried further by installing and operating temporary pumping stations at the so-called Benedek-lock, which is located in the 1+004 km section of the main canal. Currently it is the Benedek-lock that is responsible for stopping flood waves. (Within the framework of an investment project, an estuary lock/floodgate is being constructed right now.)

Along the Dong-ér main canal a large quantity of inland excess water can be retained. With the Péteritó-lock that is located in section 22+243 km, the water level of the upstream part can be regulated. By using the lock, the inland excess water can be drained into the lake Péteritó. The water storage facility for the inland excess water must be made available in the 20 October-28 February period. Lake Harkató, which is located between section 58+600 km and 60+240 km of the main canal, must cope with storing 1.5 million $m^3$ of inland excess water. Because of inland excess water protection interests, the authority ATIVIZIG can order the partial or full discharge of the lakes any time.

One of the Dong-ér main canal's most important branch canals is the Csukás-ér main canal. In addition to carrying inland excess water, treated waste water also flows in this canal. There is only little possibility for water steering in its own bed. Water can primarily be retained at the spillover structure that is located at the upper end, in the rainwater storage facility constructed in the 40+946 km section. In the lower end sections, due to the steeper slopes storage isn't possible, therefore water in the inflow canals must be stopped in the periods when inland excess water accumulates.

The function of the Gátér-Fehértó link canal, which branches off from the 6+343 section of the Csukás-ér main canal, is to lead maximum1 $m^3$/s of water from the Félegyháza canal to the Csukás-ér main canal, plus it is also the recipient of the Gátér and Tömörkény canals.

Alpár Tisza oxbow receives the water of the Alpár-Nyárlőrinc main canal until the backwater has water reception capacity. When the backwater's outflow weir, lock

No.2 must be closed because of the rising water level of the river Tisza, through the so-called Baloghalom-weir – that is situated in section 6+635 km of the main canal – as much inland excess water can be led through as the limited storage capacity of the backwater allows; this way the flooding of the backwater can be avoided. In cases like this 2 $m^3$ of water can be gravity drained into the Csukás-ér main canal via the Csukásér-Nyárlőrinc link canal. With regard to the endorheic condition, the intake capacity of the backwater is maximum 4.0 million $m^3$. As for the Alpár-Nyárlőrinc main canal, water can be retained until the 8+800 km section in the meadows and grazing land along the main canal.

## Suggestions for the changes of water control practices

By utilising the available numerical modelling capacity (taking into consideration the priorities emerging in connection with managing the inundations and with the inland areas, plus the involvement of areas capable of retaining water), the following suggestions can be made for the transformation of the water control system (Kozák 2013, 2016):

- In the future, the inland excess water security of towns, villages and inhabited areas must be improved
- The accumulation processes must be delayed, primarily by applying lock-ups in the upstream sub-catchments.
- Water retention is the most effective in the areas along the canals, which have the right morphological characteristics and land use types.
- When selecting the areas designated for retaining water, it is best if those areas are used that don't increase the inland risk, such as those that fall into the 'unutilised' or 'meadow, grazing land' cultivation categories.
- Consent must be obtained from the owners of land suitable for retaining water.
- In planning the water retention, the formation of high water depth must be avoided.
- As for the utilisation of the water quantities retained, it must be taken into consideration that the daily evaporation rate can be 10-15 mm in the summer period.
- After development work, the Gátér-Fehértó link canal will be suitable for carrying large quantities of water (~3,1 $m^3/s$), by this reducing the risk of inland excess water accumulation.