Water resource management problems and their possible solutions in the Lower Tisza river basin Water for the landscape, but from where, how and at what cost?

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Abstract: *One of today's biggest challenges is to manage the extremes in water resource management associated with climate change. Central Europe and Hungary are among the regions most affected by the impacts of water management extremes. The study area is one of the most vulnerable regions of Hungary, with a high climate sensitivity. Although there is a significant network of infrastructure in place to mitigate water shortages, it is both overstretched and burdened by significant operating costs. The recent energy price explosion has focused attention on the operational issues of these systems. However, for areas beyond their reach, only locally available primary and secondary water resources offer the potential for prevention and mitigation. These have a limited reach and are costly to use. One of today's popular slogans is 'water to the landscape', and the paper will discuss the possibilities and limitations of this in the sample area.*
Keywords: *WATER RESOURCES, CLIMATE CHANGE, WATER SCARCITY, PRIMARY WATER RESOURCES, SECONDARY WATER RESOURCES, IRRIGATION*

1. Introduction

Water resource management has always been a focus of interest. This interest has become more intense and has become a priority issue as water scarcity has worsened. It is typically approached from the water resources side, but a complex analysis of the issue is needed to approach it properly, although this is often not done.

The primary expectation when considering the issue is that efforts should be made to maintain water resources in place, but these interventions alone rarely lead to long-term results because the impact of all elements of the hydrological cycle must be taken into account. Such analyses often underestimate the role of natural factors that cause water stress, even though their impact can be many times greater than that of factors that reduce water resources (e.g. evaporation). It is essential that such effects are taken into account when developing long-term sustainable measures.

The changes experienced due to climate change affect all elements of the hydrological cycle [1]:

- the amount of precipitation, its spatial and temporal distribution,
- changes in the extremes and average characteristics of temperature,
- evapotranspiration and its intensity,
- the amount and distribution of runoff over the year,
- the amount of soil moisture, ground and deep water.

The increase in the scale of water scarcity will exacerbate situations that are likely to occur in areas already water scarce.

2. Short description of the study field

The study area is located in Europe, in Hungary. In the country, 12 regional water management organisations coordinate and implement the state's water management tasks. The tasks cover:

- maintenance, organisation and enforcement activities related to water damage management (floods, inland floods, droughts, water quality damage),
- identifying, conserving, developing and ensuring the use of surface and groundwater resources,
- monitoring and coordination of water management activities of local governments,
- assisting in the activities of public authorities in the field of water management,
- operating environmental monitoring systems for hydro-meteorological elements,
- the operation, maintenance and development of infrastructure systems to meet agricultural water needs.

The inspections were carried out in the operational area of the Lower Tisza Water Directorate (ATIVIZIG).

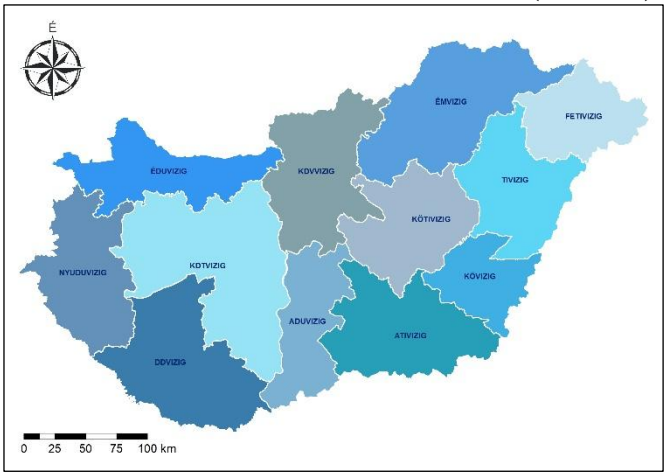

Figure 1 *Operational area of Water Management Directorates Source: ATIVIZIG*

The inspections were carried out in the operational area of the Lower Tisza Water Directorate (ATIVIZIG).

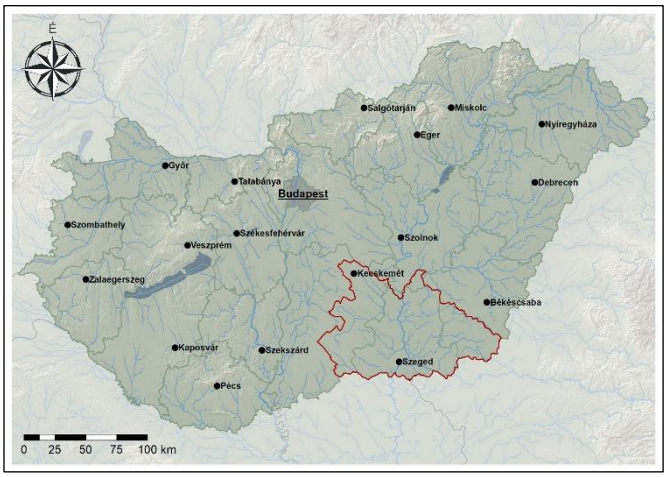

Figure 2 *Operational area of the Lower Tisza Rural Water Management Directorate, Source: www.ativizig.hu*

The country's geography means that 95% of its surface water comes from upstream countries. Within the country, ATIVIZIG's area of operation is located in the south-eastern part of the country, in a low-lying area of approximately 8 400 km2 .

Based on measurements taken since 1901, annual rainfall totals

have ranged from a minimum of 369 mm in 1983 to a maximum of 914 mm in 2010. The average multiannual rainfall over the reference period 1981-2010 in force in the area covered by the Directorate is 546 mm. The distribution of precipitation over the year is characterised by the fact that 40 % of precipitation falls in the winter and 60 % in the summer. The annual rainfall pattern is characterised by a maximum in early summer (May-June), followed by a secondary maximum in late autumn due to the Mediterranean effect (which may also be missed, as it has a probability of 20-30 %). The minimum rainfall is in the winter/early spring period. However, this average situation rarely occurs. It is typical that shorter or longer periods (3-6 months) are sometimes droughty and sometimes very abundant.

Due to the minimum precipitation during the winter period, snow cover of significant and persistent thickness is rare. The average maximum snow thickness is around 20 cm.

The mean annual air temperature is +11,2 °C. The southern areas are 0,2-0,4 °C warmer than the northern areas, with a uniform air temperature in between. The difference between the mean temperature of the coldest and warmest years is less than 5 °C. The coldest year had a mean temperature of 8.6°C and the warmest year 12.4°C.

The average number of sunny hours per year is 2100 hours. Sunshine duration is also evenly distributed over the area, with only a slight downward trend towards the north-east, where the annual number of sunshine hours is slightly below the mean.

Ground frosts typically occur in the period from December to early March. Based on data from the 1960s and 1970s, the average number of days with ground frost during this period is 60 days, with 25 days in January and 15 days in December and February, the months with the lowest temperatures. The maximum depth of ground frost averages 25 cm, reaching 60-70 cm in extreme cases.

Groundwater levels are on average 2-4 m below the surface. Due to climatic factors, the annual groundwater flow is characterised by a maximum in late spring and a minimum in autumn. The maximum groundwater levels (NV) are sometimes less than 1 m below the surface. These areas occur in patches in the exempted floodplain, in the Tisza valley. The groundwater levels in the settlements in these areas (Makó, Hódmezővásárhely, parts of Szeged, Mindszent, etc.) are particularly high. The highest groundwater levels were recorded in 1940-1942, 1956, 1966-1967, 1970-1971 and 1975, when groundwater levels were closer than 100 cm to the ground surface. The horizontal flow rate of groundwater is low, less than 100 cm per day. Since the 1990s, there has been a significant decline in groundwater levels, primarily due to meteorological changes and hydrocarbon exploration activities in the area [2].

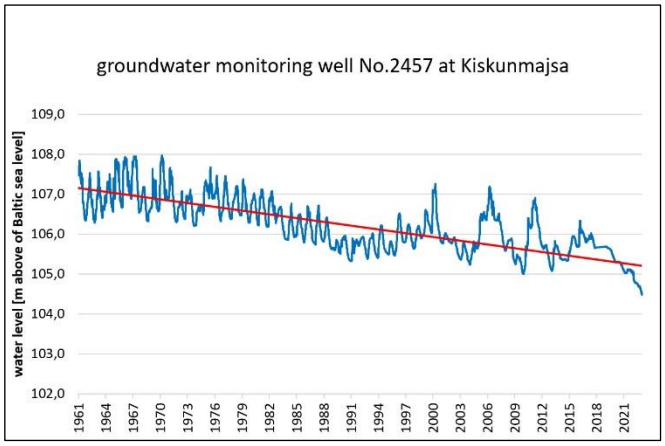

Figure 3 *Changes in groundwater levels in the area of Homokhátság located in the Danube-Tisza Interfluve, on the right bank of the Tisza River, Source: own editing*

There are three rivers in the study area: the Tisza, the Maros and the Hármas-Körös.

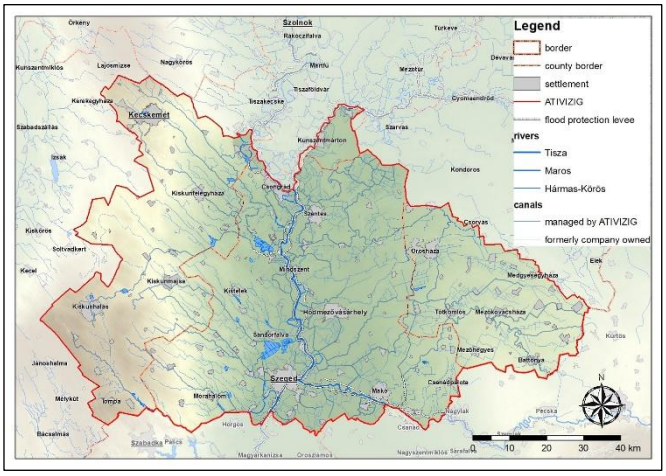

Figure 4 *Watercourse network of the study area, Source: ATIVIZIG*

Of all the rivers, the Tisza has the highest flow capacity, with maximum values of (Tabl.1.):

Table 1 *Typical river flows in the study area*

Name of river, Station	Maximum of discharge [m^3/s]	Discharge in August with 80% durability [m^3/s]
Tisza, Szeged	4200	207
Hármas-Körös, Kunszentmárton	1500	30,6
Maros, Makó	2500	62,8

Authorisiations for the use of the water resources are issued on the basis of the water yields available in August at 80% capacity. It is important to note the fact that these water flows run off below the banks of the river banks at water levels of 2-4 metres, and can therefore be delivered to agricultural users by means of cask pumping stations. The availability of river water resources is significantly reduced by the following impacts:

- riverbeds are experiencing significant bed subsidence, with subsidence rates of up to 1-1.5 metres over 5-10 years,
- the area is located in the lower reaches of rivers and is therefore particularly affected by the effects of the upstream dams, especially on the lower reaches of the Maros, where some 30 dams have been built on the Romanian territory.

These adverse effects have resulted in river water levels rising by up to 10-12 metres during periods of water scarcity, instead of the average of around 6 metres.

The surface water network in the area covers a total length of about 7000 km. These typically serve to drain stormwater, but the flow of these watercourses is significantly reduced during periods of low tide, leaving them without usable surface water resources during such periods.

3. Effects of the climate change and the quantity of the water shortage

Climate change has resulted in a small decrease in annual precipitation, but there is a significant change in its spatial and temporal distribution. Instead of the previous uniform distribution of precipitation, there is a significant spatial variation in annual precipitation, especially in areas vulnerable to water scarcity (Fig. 5).

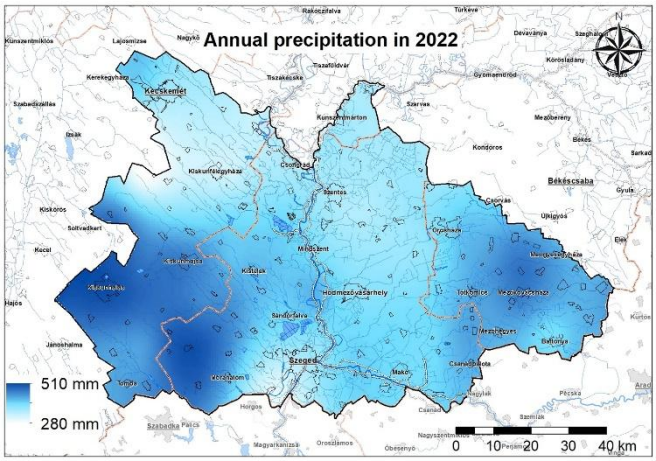

Figure 5 *Distribution of annual rainfall in water scarce 2022, Source: ATIVIZIG*

There is also an increase in average temperatures, particularly in areas already affected by water scarcity (Fig.6.).

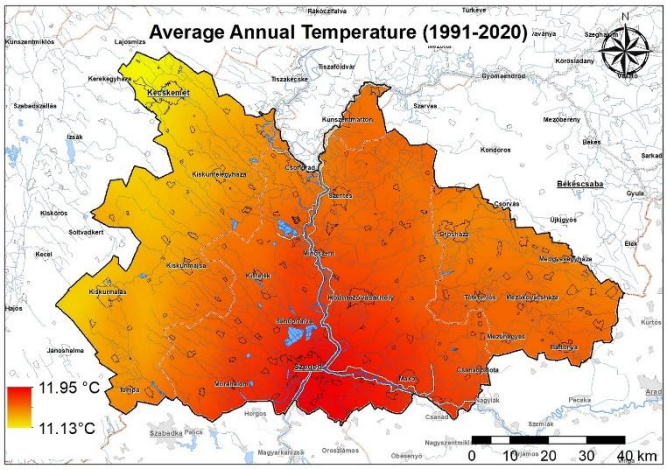

Figure 6 *Average annual mean temperatures 1991-2020, Source: ATIVIZIG*

Evaporation directly affects surface water resources, while groundwater is indirectly affected. The potential evaporation in the extremely droughty year 2022 is illustrated in the figure below (Fig7):

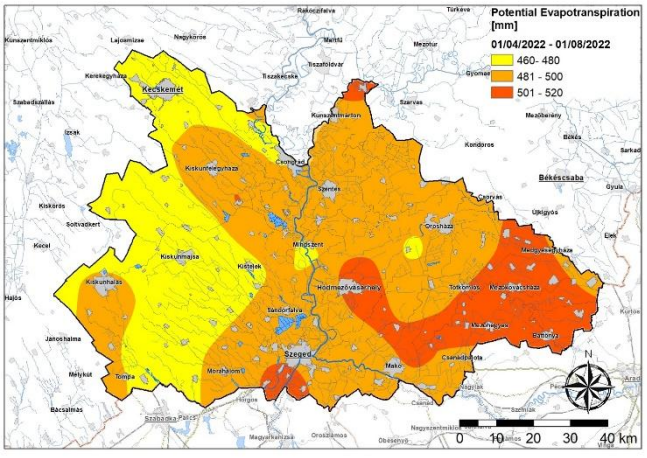

Figure 7 *Spatial distribution of potential evapotranspiration values in 2022, Source: ATIVIZIG*

The extent of the drought in 2022 is illustrated by the annual cumulative precipitation deficit in the study area.

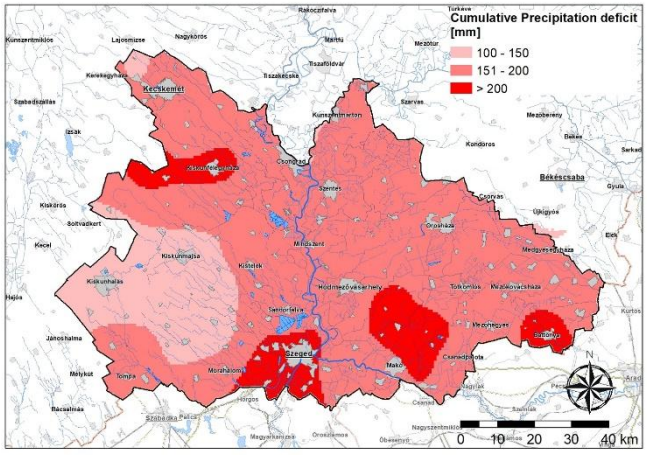

Figure 8 *Cumulative rainfall deficit in 2022, Source: ATIVIZIG*

In Hungarian practice, the PaDI [3] has been used to characterise drought in previous periods, while from 2019 onwards the Hungarian Drought Index (HDIs) has been used. The study area, typically located in the drought-prone area of the country [4]. The spatial distribution of HDIs is illustrated in Figures 9-10.

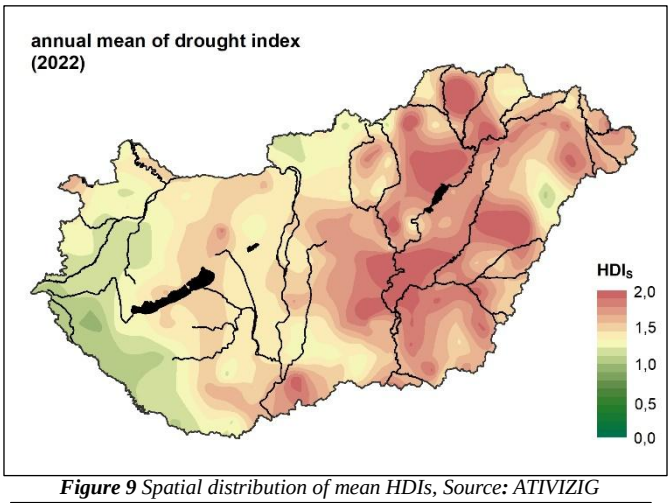

Figure 9 *Spatial distribution of mean HDIs, Source: ATIVIZIG*

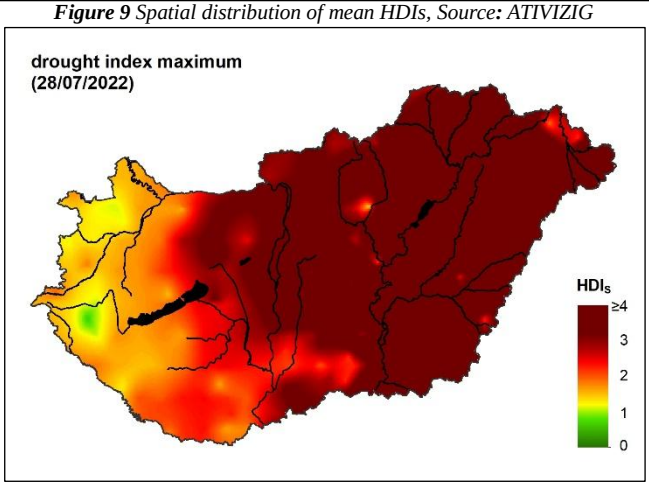

Figure 10 *Spatial distribution of maximum HDIs, Source: ATIVIZIG*

The temporal distribution of drought in 2022 has produced extraordinary extremes. In the study area, there were a total of 26 non-drought days during the year. The extreme meteorological conditions have had a significant impact on groundwater resources, resulting in further declines in groundwater levels. Groundwater levels for the period 1991-2020 were further reduced by the drought of 2022. This is illustrated by the groundwater levels in May 2023 (Fig.11).

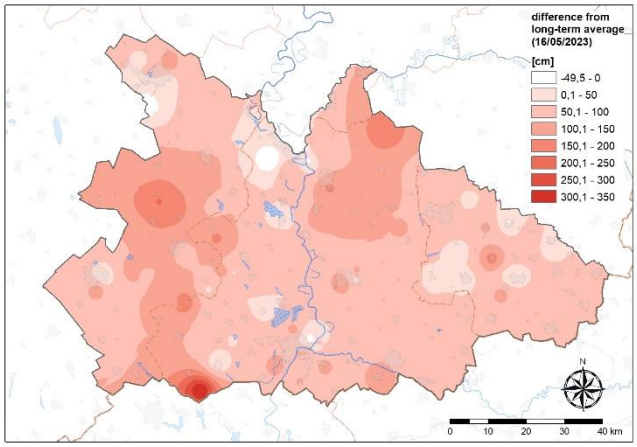

Figure 11 *Groundwater aquifer status compared to the 1991-2020 average, Source: ATIVIZIG*

An analysis of groundwater aquifer levels shows that a 1 m drop in groundwater aquifers results in a loss of about 4 billion m^3 of water resources. This trend has practically eliminated the real use of groundwater resources in some areas (e.g. in Kecskemét the 600 cm deep groundwater well has dried up).

4. The current infrastructure systems against the drought, and their problems

Irrigation systems have been built in the area over the past 60 years to meet agricultural water needs. These primarily meet the water needs of arable crops. In the study area

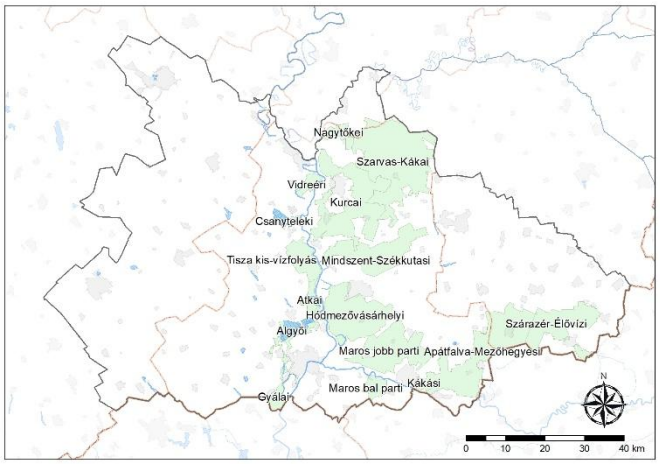

Figure 12 *Scope of irrigation systems, Source: ATIVIZIG*

The operation of irrigation systems will supply significant quantities of water to meet agricultural needs. In 2022, a very drought-prone year, around 400 million m^3 of water was supplied nationally. Of this, more than 100 million m^3 was delivered to farmers in the study area.

Due to the topography of the terrain, these systems are typically able to deliver water to farmers' land at higher elevations by pumping from rivers or by operating intermediate pumps along canals. These systems are equipped with pumping stations, but their operating costs (mainly due to recent changes in energy prices) result in significant water charges (in Hungary, users do not have to pay for the water supplied, but have to recover the costs incurred in transporting the water), which have to be paid by the users (Fig.13).

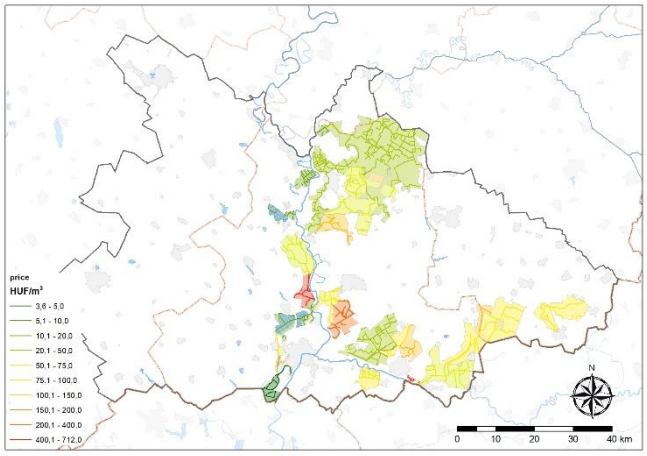

Figure 13 *Distribution of water prices by irrigation system in 2023, Source: ATIVIZIG*

Most of the water resources available for use are along rivers. However, their gravity discharge is only possible for short periods due to the subsidence of river beds, as illustrated by the hatched red line in Figure 14.

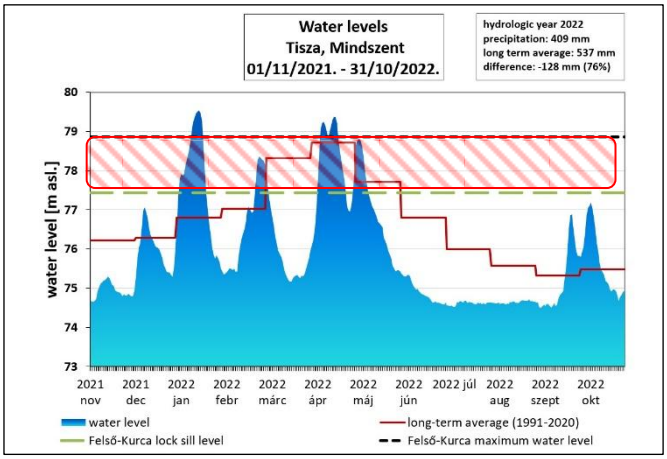

Figure 14 *Temporal distribution of gravity outlets on the Tisza River, Source: ATIVIZIG*

The reach of gravity outlets is very limited (around 1000 km^2) due to topography, as illustrated in Figure 15:

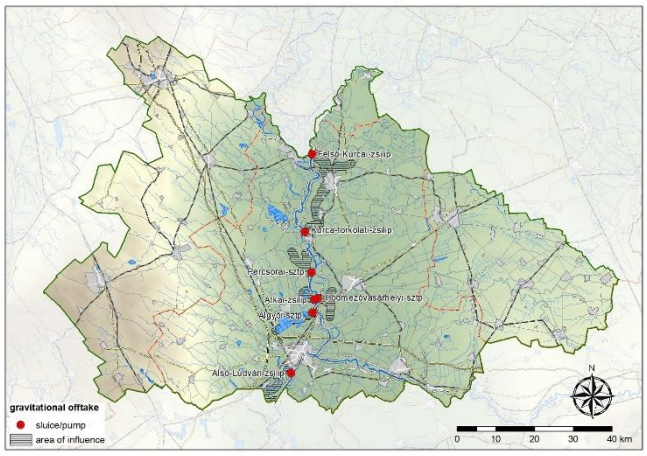

Figure 15 *Scope of gravity outlets, Source: ATIVIZIG*

In addition to the irrigation systems installed, there is significant potential for discharges of used water from municipalities. The source of these is treated wastewater discharged by municipal drinking water and industrial water uses based on groundwater resources. Their volume can generate significant stocks for larger agglomerations. It is important to note that these can be used to mitigate water shortages only after adequate treatment. The use of such waters in agriculture is limited by public health regulations. At present, these water resources are discharged into the surface water drainage network and typically help to replenish groundwater supplies through infiltration. Practical experience shows that infiltration is most effective in large reservoirs in replenishing groundwater supplies. This effect is less pronounced along canals. It should be noted, however, that in Hungarian practice, if used water is retained in a canal or reservoir, all landowners must legally contribute to the flooding of the area in order to retain the water. If 100% of the owners do not contribute, the retention of the water cannot be achieved. Although the overwhelming majority of landowners are in favour of flooding for water retention, in many cases such a plan fails due to the opposition of 1-2 landowners.

A summary diagram of the reaches affected by gravity recharge, pumping systems and municipal treated water is shown in Figure 16.

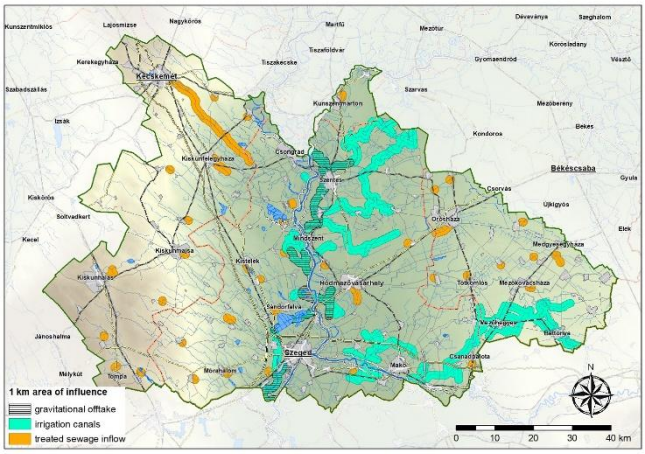

Figure 16 *Scope of the areas to be covered by water recharge, Source: ATIVIZIG*

If the areas that can be supplied with recharge (Fig 16) are subtracted from the spatial distribution of cumulative precipitation deficits (Fig 8), we can get an idea of the spatial limitation of recharge.

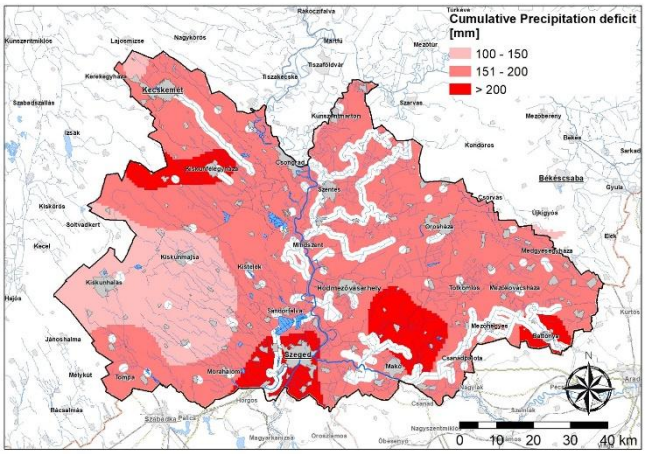

Figure 17 *Difference between recharge areas and cumulative precipitation deficit in 2022, Source: ATIVIZIG*

Figure 17 shows that an area of about 1200 km^2 (14% of the total area) is covered by the water compensation schemes, but 7200 km^2 (86% of the total area) cannot be included in the coverage of the water compensation schemes. In the period January-August, 150 mm of water would have been needed to recharge 1.09 km^3, i.e. **1.09 billion m^3** (compared to **0.1 billion m^3** for the whole year). Losses during operation are not included in the calculation!

4. Next steps, the possible aims

Based on the studies carried out, it can be concluded that the study area is not covered by the available water resources or the water supply systems that convey them. The available infrastructure and irrigation systems make surface water resources accessible on 10-15% of the total area.

The objectives needed to improve the situation should be considered in the following spatial breakdown:

- for areas already included in water replenishment,
- for areas not included in water replenishment,
- land use issues,

<u>For areas already included in water replenishment:</u>

- For systems already in operation, the aim should be to reduce operating costs, preferably while reducing energy dependency. A good solution could be to use a solar energy generation system to help supply the pumps.
- As most systems are built from open sewer networks, efforts should be made to reduce leakage losses. Although reliable technical solutions are available, these can be implemented at high unit costs, which further increase the cost of water services.
- Efforts should be made to increase efficiency in water supply systems. To this end, effective water demand management should be developed, in which the maximum possible coordination of water demands in space and time is implemented.
- In the case of gravity outlets, technical improvements are needed to ensure that gravity operation is possible for as long as possible.

<u>For areas not included in water replenishment:</u>

- The available water resources in the catchments concerned, which are available through pooling, do not allow for predictable management, as a steady increase in evaporation is expected due to rising temperatures. However, even under these conditions, efforts should be made to maintain the surface water resources in place, as appropriate.
- As evaporation is very high in the areas concerned, land use should be managed in such a way that no till cultivation is used. In this way, it is possible to reduce water deficits during evaporation.
- Efforts should be made to recycle as much as possible of the used water available in the area. In the reuse of used water, it is important to determine the appropriate purification efficiency associated with the use.
- Groundwater dams constructed perpendicular to horizontal flow directions can have a positive effect in raising groundwater levels. These can be used to achieve effective groundwater level elevations over

longer periods. Such interventions should always be subject to a detailed impact assessment. Their consequences should be widely explored.

- Where water demands are sufficiently concentrated in winter and free water resources are available to meet them, either the development of existing water recharge systems or the development of new water recharge systems may be justified. In all such cases, the water demand that can be met and the operating costs of the improvements should be determined in advance..

Land use issues:

- In relation to land use, long-term visions/societal expectations that require land use changes should be identified.
- Land use planning should be used as a basis for identifying the societal expectations for the operation of water systems, on the basis of which the technical tasks can be carried out. The necessary interventions on the water system elements should then be implemented.
- The expectations of each element of the water system must be precisely defined and the owners/managers of each element must adapt their activities accordingly.
- Modifications to tillage techniques should be implemented as necessary to reduce evaporation.
- Efforts should be made to retain stormwater runoff. Due to the high evaporation losses in the area, it is recommended to retain water preferably below the surface, using the soil's water storage capacity.
- Land use should be chosen and modified to reduce or at least delay run-off.

3. References

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