WATERS

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The hydrosphere comprises continental surface and subsurface waters that are in constant motion between the atmosphere, lithosphere and biosphere. The hydrosphere covers approximately 70% of the Earth's surface area and consists of oceans, seas, lakes, ponds, rivers and streams. As such, water is an indispensable condition for life, so the quantity and quality of available water resources are of paramount importance.

The Carpathian Basin is one of the world's most closed basins, surrounded by high mountain ranges, with narrow gates. The endorheic composition explains the particular hydrographic characteristics found in the basin. Surface and groundwater forming and discharging in the basin (excluding the Olt and Dunajec rivers) is collected by the Danube River and transported to the Black Sea, primarily through the Iron Gates mountain pass. The Danube River, entering and leaving the narrow gate, divides the river network of watercourses. Within the basin the left-bank side watercourses collect the waters flowing through the Carpathians, while the right side waters are of Alpine origin, thus their hydrographic regime is of Carpathian and Alpine nature.

Spatially and temporally, societies are in constant contact with water. This relationship highlights a complex system of coordination between natural conditions and societal needs, commonly known as water management. The history of water management is as old as the history of human society. Human activities such as frequent water extraction affect both the quantitative and qualitative aspects of the natural variability of water resources which finally influences the standard of life within society.

In Hungary, a slogan was created stating, 'Water is life, let us care together!' which reflects a comprehensive effort made by Hungarians through great interest in water care that is in accordance with the directives of the EU. 'Water is life', but only when it is utilised at the right quality and quantity. The delivery of water is one of the most important yet costly elements of our lives. Rivers, streams, lakes and groundwater not only represent natural resources but also social and economic values as well as income-generating and cost-effective opportunities, however, this resource is limited. In order to provide clean drinking water for everyone in the future, and to preserve rivers and lakes as vital elements of our lives and landscape, we must make efforts to protect waters and improve their condition.

Surface water volume, water balance

Hungary occupies the lower part of the Carpathian Basin roughly along the middle of the Danube River basin. It also attracts rivers from the west, north and east, with all its beneficial and disadvantageous consequences.

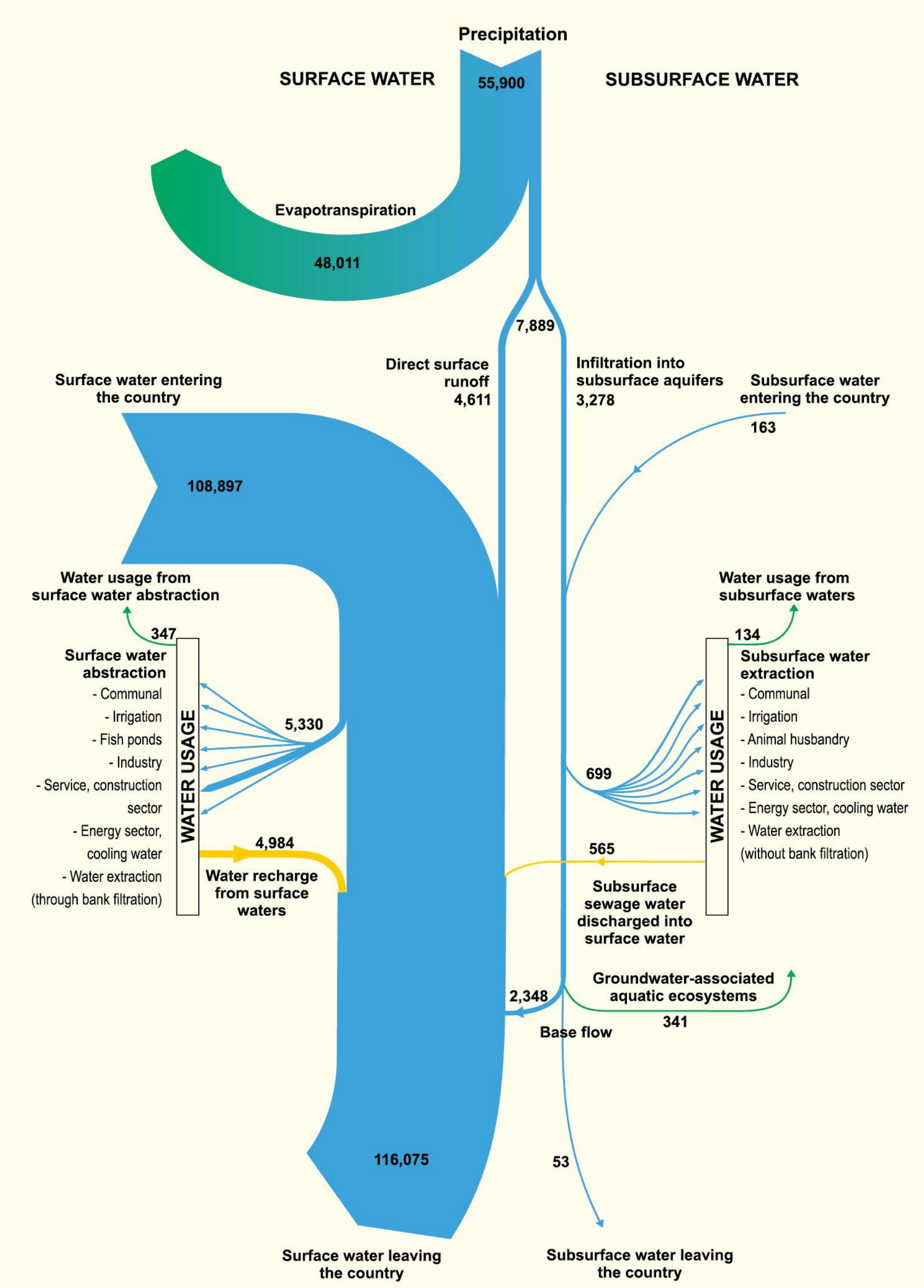
A significant part of the country's terrain is a low-sloping plain that is usually prone to flooding from several directions, simultaneously from the surrounding mountains. When compared to Alpine rivers, the rivers of the Carpathian Basin are more extreme watercourses, where the occurrence of higher water levels and floods are often replaced by low water levels that are sometimes accompanied by drought due to minimal rainfall and significantly higher evaporation in low-lying regions. Water scarcity is compensated through irrigation whereby water is conveyed long distances due to the small gradient of the surface. At the same time, low-lying regions allow a low level of water retention and storage as compared to the needs required. Therefore irrigation water is often diverted to areas that had excess water a few months earlier.

The natural flow of the plain river sections is meandering, which is necessary to maintain the balance of sediment transport and support its current biotic ecosystem. In order to reduce flood areas and increase flood safety have resulted in limited development of bends and shortened the length of rivers, causing deepening of the river beds and the depletion of the wildlife of new artificial river sections.

1 THE CATCHMENT AREAS IN HUNGARY, THEIR MULTI-YEAR MEAN DISCHARGE AND SPECIFIC RUNOFF AT THE ESTUARIES OR DISCHARGE AT THE BORDER (BASED ON DATA FROM 1981 TO 2010)

Name of River	Multi-year mean discharge (m^3/s)	Multi-year mean discharge in Hungary (m^3/s)	Hungarian catchment area (km^2)	Specific runoff of the entire catchment ($l/s/km^2$)	Specific runoff of the Hungarian catchment ($l/s/km^2$)
Duna	2,328.0	60.4	38,915	11.26	1.55
Tisza	873.0	60.3	45,010	6.26	1.34
Dráva	508.0	23.7	6,140	13.47	3.85
Maros	181.0	1.2	2,100	5.90	0.57
Szamos	135.0	0.6	338	8.54	1.74
Bodrog	119.6	2.8	969	9.70	2.91
Hármas-Körös	102.9	11.4	12,702	3.75	0.90
Sajó	63.0	11.7	4,449	4.85	2.64
Kettős-Körös	58.4	1.5	1,715	5.57	0.88
Rába	47.8	14.2	5,538	4.73	2.57
Sebes-Körös	38.1	3.5	3,438	4.03	1.01
Fekete-Körös	33.2	0,0	12	9.66	1.02
Hernád	31.9	2.3	1,029	5.85	2.23
Fehér-Körös	23.2	0.1	89	5.16	1.02
Sió	19.2	19.2	14,898	1.29	1.29
Ipoly	17.5	3.2	1,504	3.40	2.15
Berettyó	13.1	2.9	2,818	2.09	1.01
Túr	12.3	0.2	82	7.10	2.20
Répce/Rábca	11.0	5.1	2,741	2.24	1.85
Lajta	10.2	0.1	41	4.79	1.36
Zagyva	9.9	9.9	5,559	1.78	1.78
Kapos	8.9	8.9	3,258	2.72	2.72
Kraszna	8.2	1.0	832	2.57	1.17
Zala	7.6	7.6	2,586	2.93	2.93
Marcal	7.3	7.3	3,125	2.32	2.32
Bódva	6.5	3.3	868	3.66	3.78
Hortobágy-Berettyó	4.7	4.7	5,125	0.92	0.92
Tarna	4.4	4.4	1,954	2.24	2.25

2 NATIONAL WATER BALANCE IN HUNGARY
BASED ON DATA OF 2001 TO 2010 (MILLION m^3/YEAR)



In the river basin system of the Danube, the second largest river basin is the Tisza, followed by the Sava and thirdly by the Drava.

An important hydrographical characteristic is specific runoff, i.e. the amount of water flowing from the unit surface, which shows the amount of a given part of the river basin that contributes to the total runoff per unit area. Specific runoff 1 of streams is related to both climate and surface-relief.

In Hungary, specific runoff has an average of 1.59 l/s km², but this average significantly differs across the country. The driest areas of the Alföld (Great Hungarian Plain) reach only 0.7 l/s, while in Western Transdanubia it reaches between 5.5 to 6.0 l/s. There are even bigger differences in the Danube's upstream (outside the border of Hungary) catchment area, where 30 to 40 l/s values are recorded in the Alps.

Water cycle – which is accommodated by the atmosphere, ground, watercourses, land cover, rocks of the Earth's crust and oceans – plays an important role in maintaining the Earth's habitats. A part of Hungary's water balance 2 includes two permanent and easily accessible water bodies: watercourses and standing waters, and subsurface waters flowing within rocks. Most of the renewable water resources come from surface water catchment areas and amount to 108,889 million m³, which is roughly 109 km³. Precipitation is the major source of water resources in the country, however, most of it is returned to the atmosphere through evapotranspiration (evaporation through vegetation). Approximately 8.2% of precipitated water is found in surface waters and 5.8% infiltrates into the ground and provides replenishment to groundwater. Together they form an increase in water resources, which amounts to an area of roughly 7.9 km³, totalling to about 6.5% of the country's renewable water resources.

The annual volume of water abstractions from surface waters is 5.3 km³, while groundwater abstractions amount to 0.7 km³. Drinking water is predominantly drawn from groundwater, while surface water is mainly used to meet high water demand e.g. industrial cooling water, irrigation and filling of fishponds. Approximately 90% of water from abstractions is returned to the environment either in the form of sewage water or grey water. The difference between the quantities removed and returned in the water balance cycle is mostly due to evaporation by the plants during the irrigation process, while a smaller part is due to infiltration into the ground and eventually to groundwater.

The smaller proportion of groundwater infiltration is then extracted for different uses. However, most of it returns to the surface: in mountainous and hilly areas in the form of springs and often over a short period of time, while in lowland areas it follows along longer pathways in groundwater flow systems. These systems provide additional supplies of water to rivers or evaporate from groundwater that is near to the surface. Moreover, groundwater plays a significant role in maintaining wetlands, marshlands and saline lakes. Particularly during low-water periods, water formations are supported by groundwater injection enabling them to provide sufficient living conditions to flora and fauna.

The water supply is continuously renewed during the movement of water in hydrological cycle however; its quantity changes depending on climatic conditions. Since water demand usually occurs at specified times as a specific quantity, available water resources can only be regarded as sustainable if they can be permanently and safely removed from the basin or extracted from groundwater layers and whose removal and utilization will not endanger ecosystems and habitats based within the same water resource.

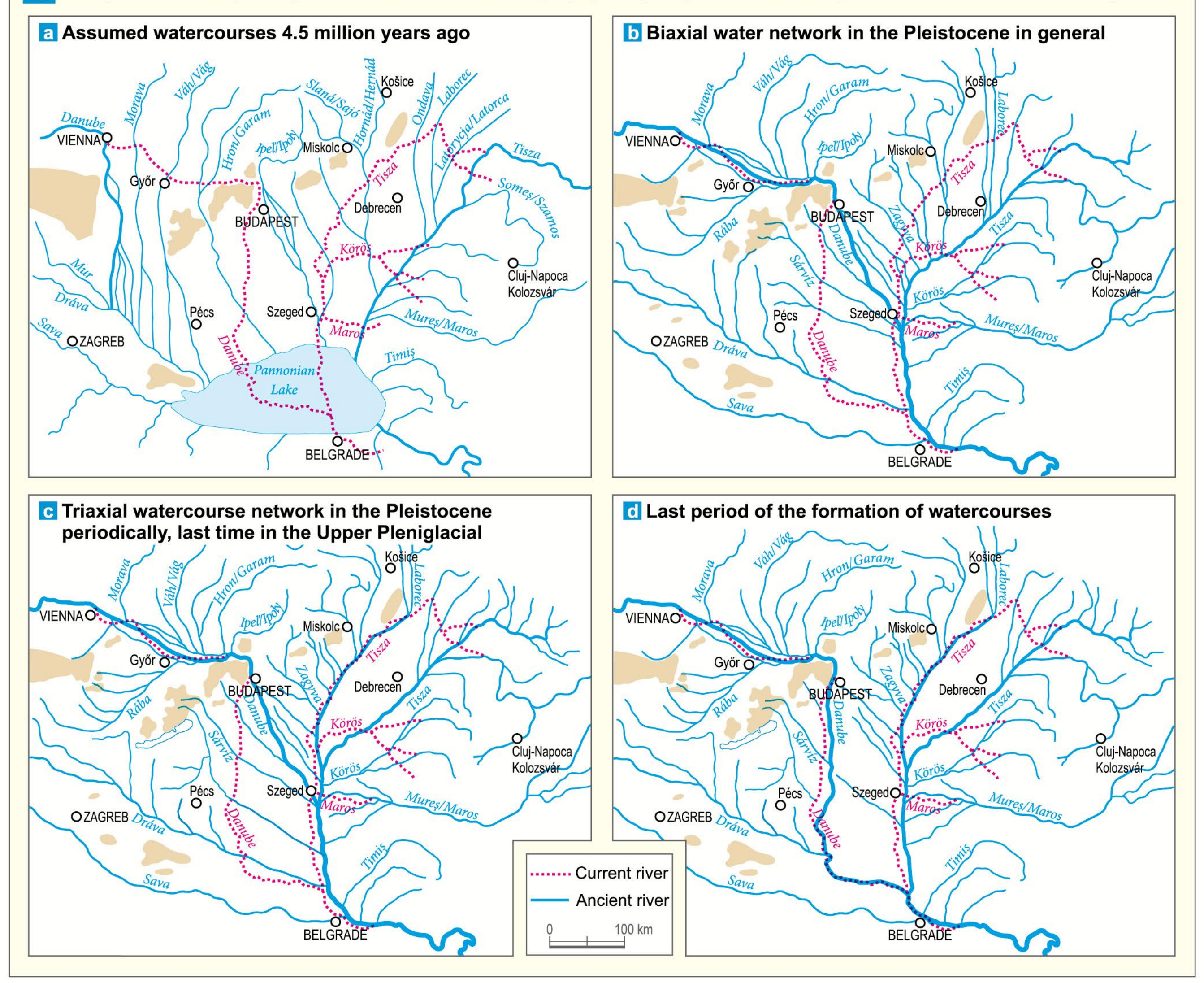
Surface water network

Rivers

The Carpathian Basin is one of the most isolated basins on Earth, with only its main river, the Danube originating from outside the Carpathian region. Almost the entire Carpatho–Pannonian Area belongs to the Danube basin 4, and the Danube – leaving the Carpathian Basin – continues to transport the collected waters towards the Black Sea. In addition to some of the smaller rivers (Dunajec, Bistrița Aurie and Trotuș) starting from the watershed of the curve of the Carpathian Mountains, there is only one major river that leaves the basin; the Olt River, which flows across the Southern Carpathians and eventually into the Danube.

The *Danube* is the second largest river in Europe after the Volga River, and in terms of its length, occupies the 35th place among the great rivers on Earth. Its total length is 2,860 km, from the source at Black Forest to its estuary at the Black Sea. Its catchment area is 817,000 km², which 8% is of Europe's territory. The Danube slows down as it enters the Carpathian Basin, depositing great volumes of sediment and building up fantail alluvial fans, on which the river itself has often changed its flow direction. Due to the uneven sinking of the basin, at some places the deposited sediment reaches a thickness as large as even several

3 FORMATION OF THE WATERCOURSES IN THE CARPATHIAN BASIN



Formation of watercourses in the Carpathian Basin

The water network developed only after the refilling of Pannonian Lake. The vast water basin was mostly filled with sediment deposited by inflow, over millions of years and as such, the gradually retracting water remained for the longest time in the south of the region. Following the withdrawal of the lake, the rivers then appeared in the dry areas. During the evaluation of a number of drillings, layers in the first water network reconstruction show the state of watercourses approximately 4.5 Mya 3a. The most striking phenomenon is the peripheral position of the two great rivers: the Danube flowed originally east of the Alps, in a southwards direction, and the predecessor of today's Tisza could flow on the eastern edge of the plain, connecting with the tributaries in an easterly course and the branches of the Bodrog. The waters of the Northwestern Carpathians (from Váh to Hornád) were flowing in south to southeast directions.

Subsequently, the unevenly submerging sub-basins attracted the main rivers. The Danube thus turned towards the Visegrád Gorge, whereby the rivers flowing from the Northwestern Carpathians were shortened, while the Rába along with the Zala headed for the basin of the Kisalföld (Little Hungarian Plain). The Danube, starting from the Pest Plain, changed its location in a fan-shaped broad band to the Szolnok–Szeged depression in the southeast and released its sediment large in thickness between the Danube and the Tisza. The Tisza was progressing along the most strongly and almost continuously descending parts of the Alföld (Körös Basin), resulting in a biaxial hydrographic position 3b.

Towards the end of the Pleistocene, due to the more intensive sinking of the Jászság–Heves region, a large tributary of the Tisza River was formed along the rivers from the north, along the third hydrographic axis 3c.

Due to the structural movements of the last 20,000 to 30,000 years, first the Danube took its present location at the edge of Mezőföld 18,000–25,000 years ago. Then approximately, 12,000–15,000 years ago the sinking of the Bodrogköz drew the Tisza to the north 3d, where it gradually occupied its current position, and finally resulted in the occupation of rivers of the Berettyó–Körös (Crișana) region at their present location.

[1] *The view of Budapest with Margit Island*

[3] *The Rába River at Győr*

[6] *The Tisza at Tiszainoka*

kilometres. Lower sloping sections (for example, between Szap and Gönyű, Dömös, Vác and Alsógöd, etc.) are characterized by sand banks and shallow formations. These pebble and sand banks change their location even today, forming smaller and larger islands. Other than this, a special section of the river is the young breakthrough of the Visegrád Gorge, south of which the bank-building character reigns. Due to the interconnection of the sand banks, smaller and larger archipelago groups developed and survived from Szentendre to the southern end of Csepel Island [1]. From Devín to Mohács, the deposited sediment is gradually getting finer, the sediment swirling in the riverbed becomes increasingly smaller grained; the size of the initially dominating pebbles decreases, and from Paks, sand becomes more dominant.

After leaving the Visegrád Gorge, the Danube is constantly eroding its right bank along its north to south flow direction, which, combined with the influence of precipitation infiltrating the loess, causes slides of its high-altitude loess walls at the edge of the Mezőföld (*Natural hazards* chapters [5] and [8]). The flat left bank, however, is a wide lowland divided only by sand-dunes and terrace islands built by the river. The maximum width of the curved floodplain from Csepel to Mohács reached 25 km before the water regulations in the 19th century. South of Paks, down to the mouth of the Drava River, reef and island formation is more intensive along the river that split into several branches. Along further sections as far as the Iron Gates, eroding high bluffs begin to reappear.

The gradient of the Danube riverbed changes significantly as the river flows through the Carpathian Basin. While the fall is 40–50 cm/km in the German and Austrian sections, from Bratislava to Szap it is 35–40 cm/km, while at Komárom (Komárno) it is only 8–10 cm/km; although it temporarily increases along the Visegrád Gorge, then again drops to 10–12 cm/km.

The Danube is fed by its left tributaries in the Carpathian Basin, namely the Váh (Vág), Nitra (Nyitra), Hron (Garam) and Ipoly (Ipleľ) of Carpathian nature with uneven water hydrographic range in their natural state. Out of them particularly the *Váh (Vág) River* [2] was 'tamed' by series of weirs. From the right, three water systems of the *Rába (Raab) River* [3] transport water of the West Transdanubian streams – Ikva, Gyöngyös–Güns, Pinka – and the smaller streams on the western periphery of the Kisalföld and of the Transdanubian Range – Répce (Rabnitz), Rábca, Marcal, Torna, Gerence – to the Danube. However, all these and other smaller right side waters (Concó, Által Brook, Dera, Vál Water) joining the Danube as far as the southern end of the Csepel Island, hardly have any influence on the water regime of the Danube or at times only during significant prolonged flood events.

Between the Ipoly and the Tisza estuary there is no major left tributary of the Danube, except for an artificial Danube Valley Main Canal, which collects the water from the creeks on the Danube–Tisza Midland Ridge and transports it to the Danube south of Mohács. On the right side there is only one major river, the *Sió* [4], joining the Danube, which is also fed by the Kapos and the Sárvíz, which regulates the water level of Lake Balaton, and plays a significant role in the development of an artificial riverbed. Larger rivers join the Danube only beyond the borders, in the southern regions of the Carpathian Basin. Among them, the following are of significance: the 749 km long *Dráva* [5], fed by the Mura, with a catchment of 40,095 km², stretching as far as the Central Alps and the 940 km long *Sava* with a 95,700 km² river basin, taking its source in the Julian Alps, running through the Dinarides (Una, Vrbas, Bosna, Drina).

[4] *The Sió River and its sluice at Siófok*

Although the Dráva and the Sava are large rivers, the most significant tributary of the Danube in the Carpathian Basin and the main watercourse of the Alföld is the Tisza; [6] with a length of 1,260 km. It originates in the Northeastern Carpathians but after a short, mountainous section, from Vylok-Tiszaújlak until it meets the Danube at Titel, it is an alluvial river. A good indication of the change of its features is, while from the source region to Vylok (Tiszaújlak), the fall of the river is 1,410 m, it changes and its fall is only 90 m to Szeged. Due to the extremely low fall, the average water velocity does not exceed 1 m/s (3.6 km/h). The slowly moving water was not able to sustain its own riverbed, so while flowing through the Alföld, the river formed huge curves. Under flood conditions, the winding riverbed was not able to discharge the multiplied volume of water and flooded the depressions as well as flat areas, while the river spread its bulky sediments onto the plane. About 12 million m³ of floating sediment was measured at Szeged but at times floods can cause this figure to multiply depending on the severity of the flood.

The Carpathians, Transylvanian Basin and Apuşeni Mountains (where Tisza's tributaries originate and flow), cover about 58% of the 157,135 km² catchment area of the *Tisza* [4] while 42% of the river basin is flat. It receives most of its tributaries in the upper reaches. As far as the Khust gate, highly fluctuating watercourses (Vişeu, Iza, Teresva, Tereblia and Rika) with Carpathian features discharge into the small river fed by two springs (White and Black Tisa). When it reaches the plain, it is forced to bypass the northern edge of the Nyírség region, while receiving its first truly significant tributaries the *Szamos (Someş)* [7], which crosses the northern rim of the Transylvanian Basin, the *Bodrog* (as a result of the merger of numerous Carpathian rivers) and the *Sajó (Slaná)* [8], is fed by the Bódva and Hernád-Hornád. From this point on, the number of tributaries decreases considerably but additional watercourses join the river on its course. On the right, only the *Zagyva* River is worth mentioning but on the left side the *Körös* River, the second largest tributary of the Tisza [9] covers 27,537 km² of the catchment area. The Hortobágy–Berettyó River flows into the lower part of Körös, which receives water supply from the Tisza through the Eastern Main Canal. To the south, its largest tributary, the *Maros-Mureş* (761 km long with a catchment area of 30,332 km²) meets the Tisza at Szeged; the most remote sources of which are found in the Eastern Carpathians [10].

[7] *The Someşul Mic (Kis-Szamos) at Cluj-Napoca (Kolozsvár)*

[2] *The Váh River at Strečno Castle*

[5] *The Dráva River*

[8] *The Sajó at Miskolc*

[9] *The Holt-Körös at Szarvas*

[12] *The view of Lake Balaton from Fonyód*

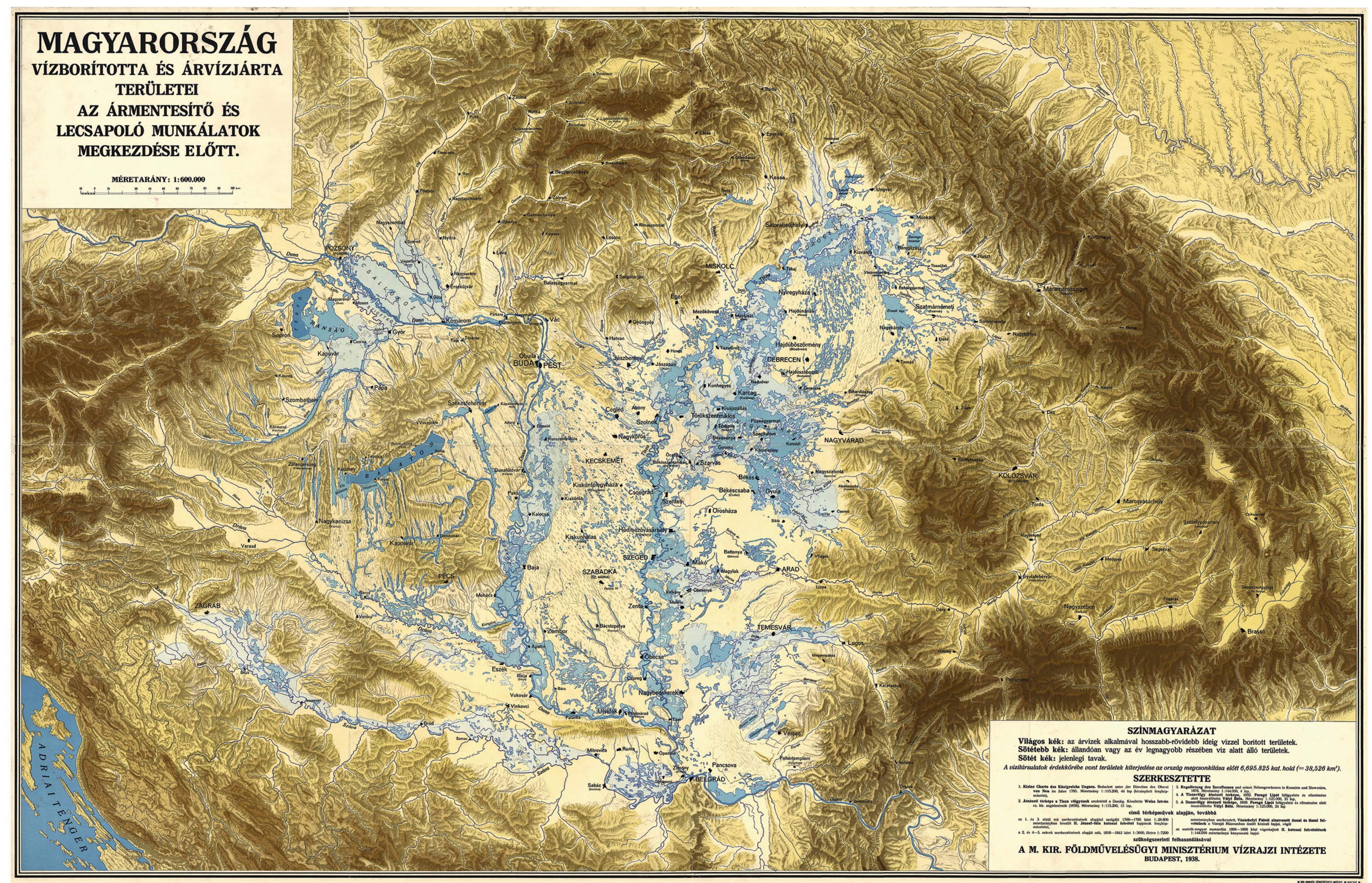
The main supply area of the Tisza is the region of the Carpathians, where it is mostly the time and speed of snowmelt in spring, or even in other seasons, and the specific meteorological conditions, such as a prolonged period of heavy rainfall which have a significant role in river flow. Large floods can develop over a short period time, especially when snow melting begins nearly at the same time in the catchment areas (moreover, melting is accelerated by extensive rainfalls), or when high waters coming from the north to northeast reach the southern slope at the same time when the Körös (Criş) rivers or the Maros (Mureş) peak at their estuaries. In such a case, flood waves flowing or colliding at the same time cause floods amplified by congestion. On the other hand, due to the slight differences in the level of the Tisza on the Alföld, there was hardly any chance of recession for the naturally spreading flood in the vast Szolnok–Debrecen–Békéscsaba area. Thus understandably, one third of the flatland section of the Tisza river basin was constantly or periodically under water [11]. These two factors – coupled with economic interests aiming at increasing agricultural land areas – led to the active river regulation and flood control activities in the 19th century.

[10] *The Mureş (Maros) at Sălard (Mureş County)*

Lakes

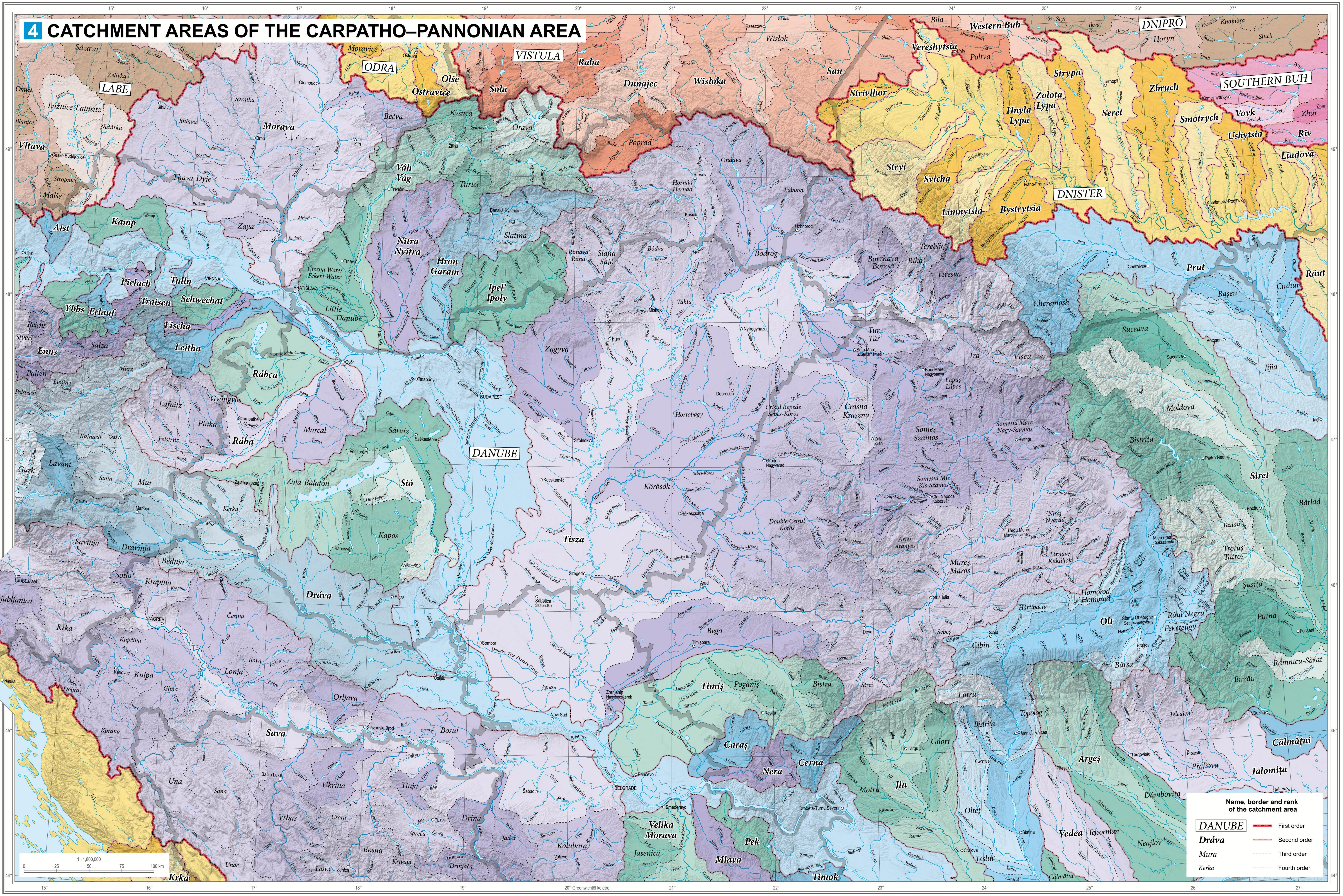
In the territory of Hungary, more than 1200 standing water bodies of different types (oxbow lakes, fishponds, mine pits, etc.) are recorded. During river regulation and flood control activities, hundreds of artificial or naturally occurring oxbows were created as a result of cutting down curves. Most of them have been filled up over the past century, while others have been preserved as lake-like features. Besides them the number of lakes smaller than approximately 0.5 ha is about 700. This number changes constantly as mine lakes are opened, natural lakes are drained, ponds and water reservoirs are built. The number of natural and artificial ponds above 5 ha is almost 200, whereas the number of lakes greater than 50 ha is only 27. The three largest existing natural water bodies today are Lake Balaton, Lake Fertő (Neusiedl) and Lake Velence.

The largest lake in Central Europe is the 76.5 km long *Lake Balaton* [12], with an average width of 7.5 km, an area of 596 km² (in case of 90 cm water level at Siófok), a mean depth of 3.36 m, and a water capacity of about 2 km³ 12. About half of drainage waters from the lake's catchment area reach Lake Balaton through the Zala River; besides this the lake is fed by about 30 more or less permanent and 20 intermittent streams. Although the latter have low water flow, their role is not negligible, as they usually reach the lake through a recreational and residential area that surrounds Lake Balaton, polluting the lake to a greater or lesser extent. The lake's extra water resources are drained by the Sió Canal, and since the Zala flows into the southwestern end of the lake and the Sió originates near the other end of the riverbed, as such, the water transported through the lake bed flushes through the two large separate pools of the lake. These two pools are separated by the narrows of Tihany, in which 10 to 12.5 m, a ditch-like depression is formed, with about 1 to 1.5 m/s water velocity occurring in the narrow part that prevents sludge deposition. Historically, Lake Balaton was much larger and had higher water level in its bays reaching deeply into the Zala valley, the Fűzfő, Tapolca and Hévíz basins, and in the south to the groves behind the offshore-bars [5]. In order to regulate the water level, Siófok's sluice was opened for operation in 1863, eliminating the natural outflow of the lake and replacing its natural watercourse with artificial regulation.



[11] *Inundated and flooded areas in the Carpathian Basin before the start of flood control and drainage works*

4 CATCHMENT AREAS OF THE CARPATHO–PANNONIAN AREA



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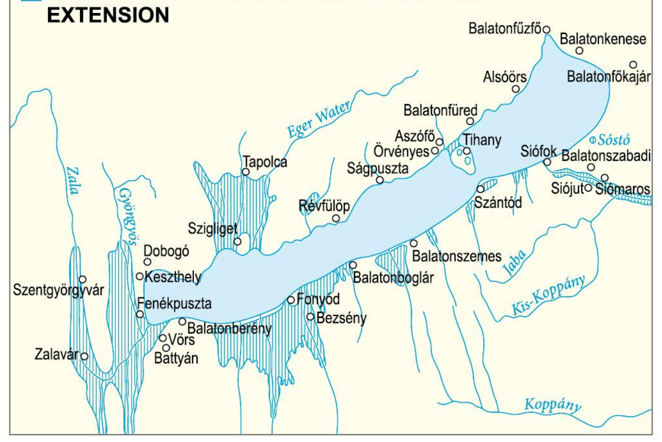
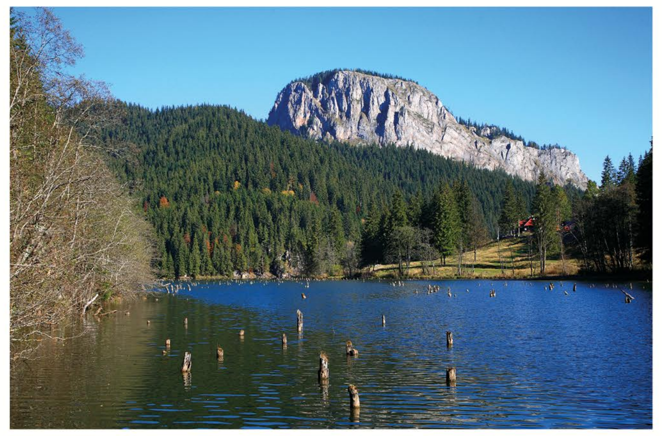
5 LAKE BALATON AT THE TIME OF ITS LARGEST EXTENSION



7 WATER BALANCE FACTOR VALUES OF LAKE BALATON

Water balance factor	1921–2016 Minimum (lake mm/year)	1921–2016 Average (lake mm/year)	1921–2016 Maximum (lake mm/year)
Precipitation	309	617	929
Inflow	236	856	1,974
Evaporation	723	897	1,073
Natural change of water resources	–281	+577	+2,031
Outflow (water drainage)	0	557	1,791
Water use	11	30	51

1 lake mm water column~600,000 m³ water volume



15 *Lake Roșu (Gyilkos)*

The fluctuation of the water level in Lake Balaton is essentially dependent on meteorological and hydrological conditions, mostly on the rate of precipitation, flow intake of water and evaporation. There is a particular phenomenon called water oscillation, which involves constant winds, blowing from the same direction resulting in longitudinal and transverse waves. The longitudinal oscillation (e.g. between Balatonfűzfő and Keszthely) can reach as much as 1 m. Transverse oscillations are smaller; typically below 50 cm. Compared to the average water depth they are of considerable height; on average 50–60 cm, during a strong storm and at times temporarily exceeding 100 cm. These have created a wide offshore bar zone in the loose sediments of the southern shore during the past 200 to 400 years, resulting in a 500-m shift of the shore.

The changes in water level of Lake Balaton have been known since 1863, following the installation of the Siófok sluice and water gauge 6. Due to the operation of the sluice, water levels show smaller, but still significant fluctuations 7. The recharge capacity of the sluice has been increased several times, last time in 1977 to 80 m^3/s, which allows for the occasional water surplus to be drained in order to mitigate excessive water level fluctuation 8. Sufficient surplus water should be stored in the lake basin so despite summer water losses, the water level should not fall noticeably low during the holiday season. The current water level regulation has been in effect since February 2016. According to this, the maximum control level of the lake is 115 cm which is ±5% in the November–April period, and 120 cm which is ±5% in the May–October period.

13 *Aerial view of Lake Fertő (Neusiedl) from near Balf*

Among the other two larger lakes, *Lake Fertő* (with an of area 309 km^2, of which about 75 km^2 is in Hungarian territory) has regulated outflow. The average lake surface area of 180 km^2 is intergrown by reed 13. As a result of the flat feature of the lake-bed, a 1 cm water level change causes a 3 km^2 change in surface area. At medium water level, nearly half of the total lake volume is sludge. Therefore, water depth varies greatly depending on the weather. The drainage and lock system built after recent drying allows the mitigation of water level fluctuation. Salt content varies between 2,000 to 18,000 mg/l seasonally and depending on the weather. Due to a rise in temperatures there

14 *Aerial view of Lake Velence*

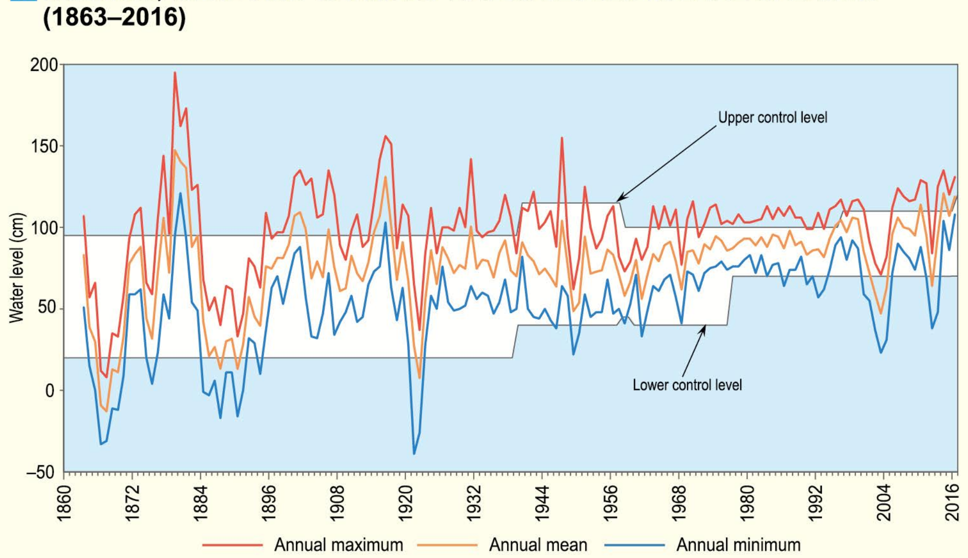
may be a risk of drying, like the case of *Lake Velence*, which fills up the flat basin (26 km^2) with an average depth of just 1.1 m. This lake is characterized by extreme water level fluctuation, slow and uneven water exchange, as well as very different water composition and water quality at various parts of the lake bed 14. The solute content of water is quite high at some places. Most of the surface area of both lakes is covered by reeds.

In addition to the above-mentioned great lakes, there are several smaller lakes in the Carpathian Basin, which vary in origin. Most of them are generated by waters accumulating in natural depressions of the surface; their life span is often very short and they are usually filled rapidly. Others were formed by sloping mass movements, landslides impounding areas, such as Lake Roșu (Gyilkos) 15 and Lake Arló. A special value is represented by low moors having hardly any open water surface (e.g. Bátorliget ancient swamp) and bogs (e.g. Lake Mohos in Kelemér or Mohos peat moss in a crater of Ciomatul Mare/Nagy-Csomád in Transylvania). However, the above-mentioned Ciomatul (Csomád) is particularly famous for its crater lake, Lake Sfânta Ana (Szent Anna) 16. Due to their ecological significance and their European uniqueness, particular mention should be made of the windswept, deflated, flat precipitation and groundwater pools, varying in size depending on the weather conditions, mainly in the Alföld. Regrettably, since the 1970s, in the heart of the Carpathian Basin, the drying up of groundwater resources resulted in the complete drying of the majority of salt lakes, the permanent damage of former ecosystems, and occasionally the dissolution of less developed carbonate sediments.

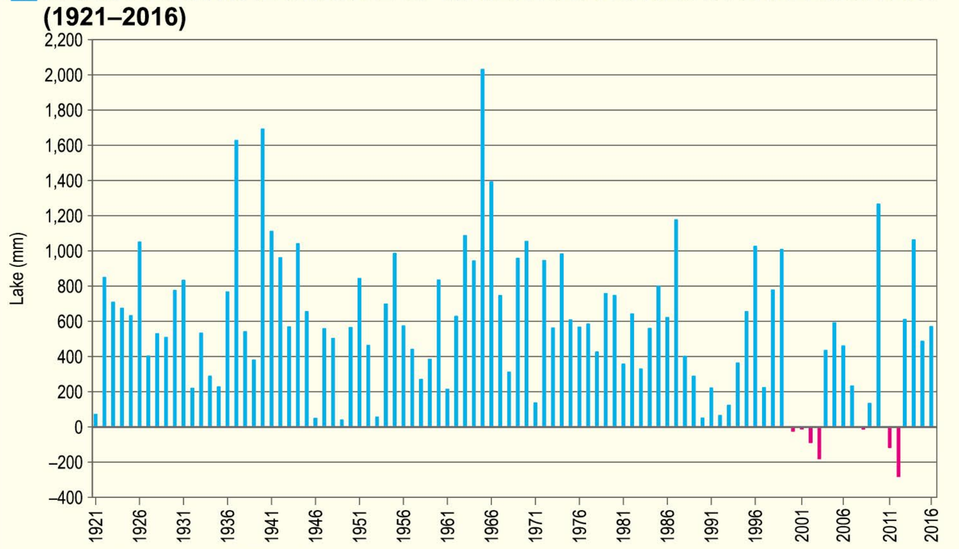
Human activities also resulted in the creation of several lakes. Such are ox bows associated with the regulation of rivers, and include mine lakes mostly with pebble, sand and clay deposits (e.g. the lakes of Délegyháza near Budapest and the 'Sunny lakes' in Senec/Szenc near Bratislava). The largest and most permanent mountain and lowland reservoirs are the results of dam constructions (on the Alföld: Lake Tisza, in Slovakia the Šírava of Zemplín, the Hrušov, Orava, Liptovská Mara, Veľka Domaša, Kráľová/Vágkirályfa Reservoir and in Transylvania the Fântânele, Colibița, Oașa and Gura Apelor Reservoirs).

16 *Lake Sfânta Ana (Szent Anna)*

6 MINIMUM, MEAN AND MAXIMUM WATER LEVELS IN LAKE BALATON (1863–2016)



8 NATURAL ANNUAL CHANGE OF WATER RESOURCES IN LAKE BALATON (1921–2016)



1 lake mm of water column ≈ 600,000 m³ of water volume

17 *Lake Tisza*

Lake Tisza is a reservoir that was created by damming the water in two phases until 1990 and thereafter the installation of the dam in 1973. The surface area of the lake is 127 km^2 in summer though this may reduce by one third after winter drainage. The northern part of its numerous small islands is used for nature conservation purposes whereas the central pools mainly for ecotourism and the southern areas for sports and recreation 17.

Groundwaters

The groundwater's of Carpathian Basin vary from, shallow to deep as well as karstic water. Based on the formations, the most extensive, interconnected strata are the Pliocene–Pleistocene basin deposits represented by gravel, sandy, muddy and clay layers. The storage system of Pliocene–Pleistocene-aged rocks – in a vertical direction – is a series of sedimentary layers from the surface to the Lower Pannonian–Upper Pannonian layers. Under this storage system, mostly sediments with poor permeability are located, which isolate groundwater aquifers from the deep-sealed, mostly carbonated rock deposits. The thickness of the Pleistocene–Holocene deposits reaches 700 m in the Kisalföld and 800 m in the Alföld. These are not divided by homogeneous water-bearing formations but by less water-bearing layers; the proportion of water-bearing layers is approximately 50% on average.

By classifying the strata of the near-surface storage system on the basis of their water conductivity, it can be established that the alluvial fans are the most permeably layers on the edge of the basins, the sandy gravel of which is transported and piled up by the rivers flowing onto the plains. The most important of them is the Szigetköz–Csallóköz alluvial fan built by the Danube in the Kisalföld with a thickness of more than 400 meters. On the southeastern edge of the Alföld, the Maros, and on the northern part of the Alföld the Sajó's alluvium can be mentioned as an example.

Under the Pleistocene layers of sand, sandstone, aleurite, clay and marl alternate, reflecting the transition of sediment formation between inland seas and rivers. This phenomenon is characteristic of the surface flats and the Transdanubian hinterland from the surface to the Lower Pannon–Upper Pannonian border. The total thickness of these sediment collections reaches 1,500 to 2,000 m in the Kisalföld and in the southern Alföld.

The recharging of groundwater resources basically determines the quantity and quality of groundwater. Water balance calculations and other studies have shown that recharge rates are low, in mid-precipitated decades it is around 50 mm/year, and in decades with even less precipitation it might not even reach half of this, and climate change will certainly result in further decline. During the 2001 to 2010 period, the volume of water infiltrating into aquifers in Hungary was 3.3 km^3/year, which was complemented by 0.16 km^3/year originating from across the borders 2.

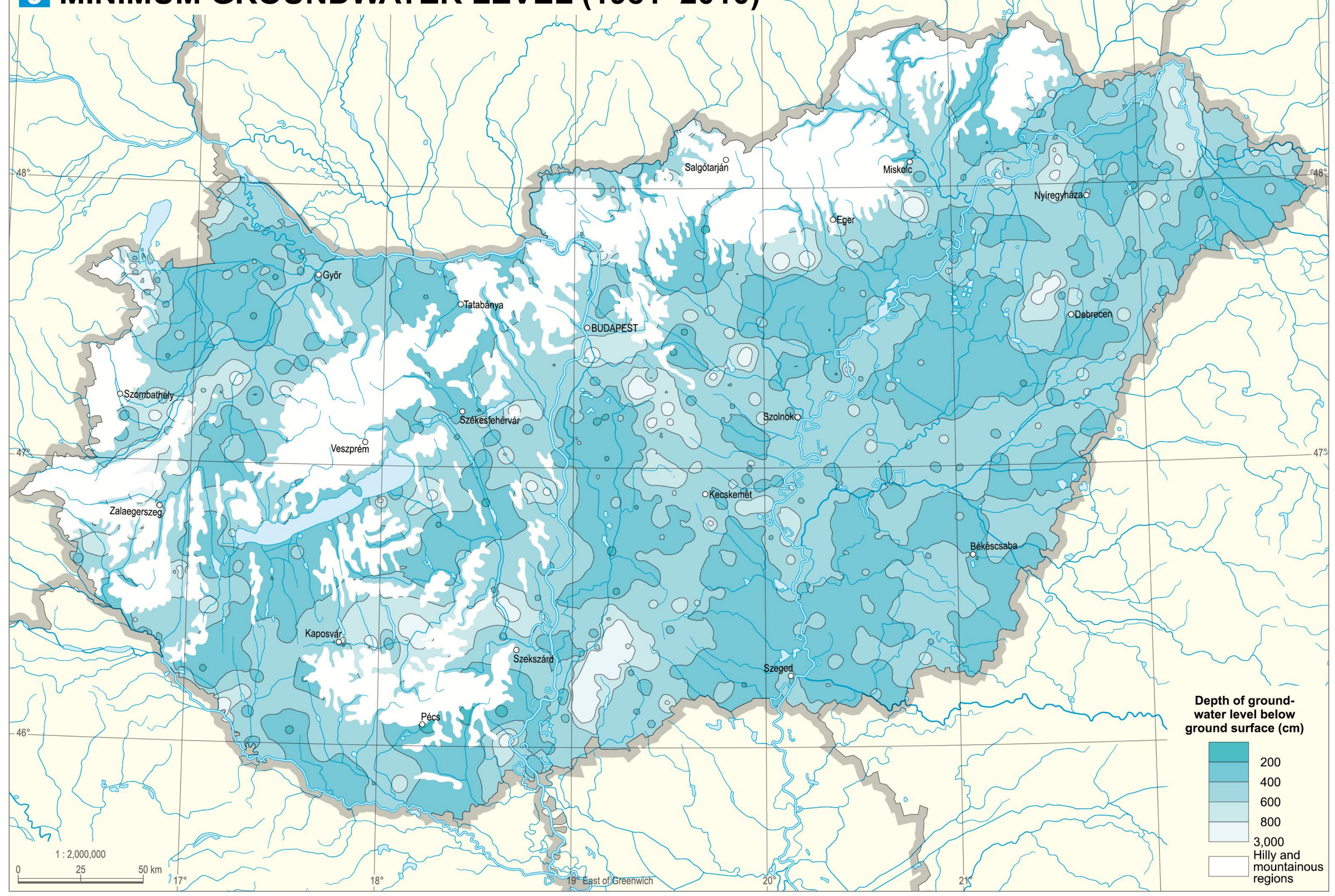
Groundwaters

Due to the unique natural conditions in Hungary – especially in the flatland areas with scarce surface waters – the easiest water supply option for centuries has been the abstraction of the widely available groundwater resources through boring of wells of various diameters and depths 18. Their significance has progressively increased with the implementation of flood protection and drainage works because regional shortages emerged in surface water resources. Until the mid-20th century, it was almost exclusively possible to satisfy the water needs of those living in the outskirts and of the farmers using this method.

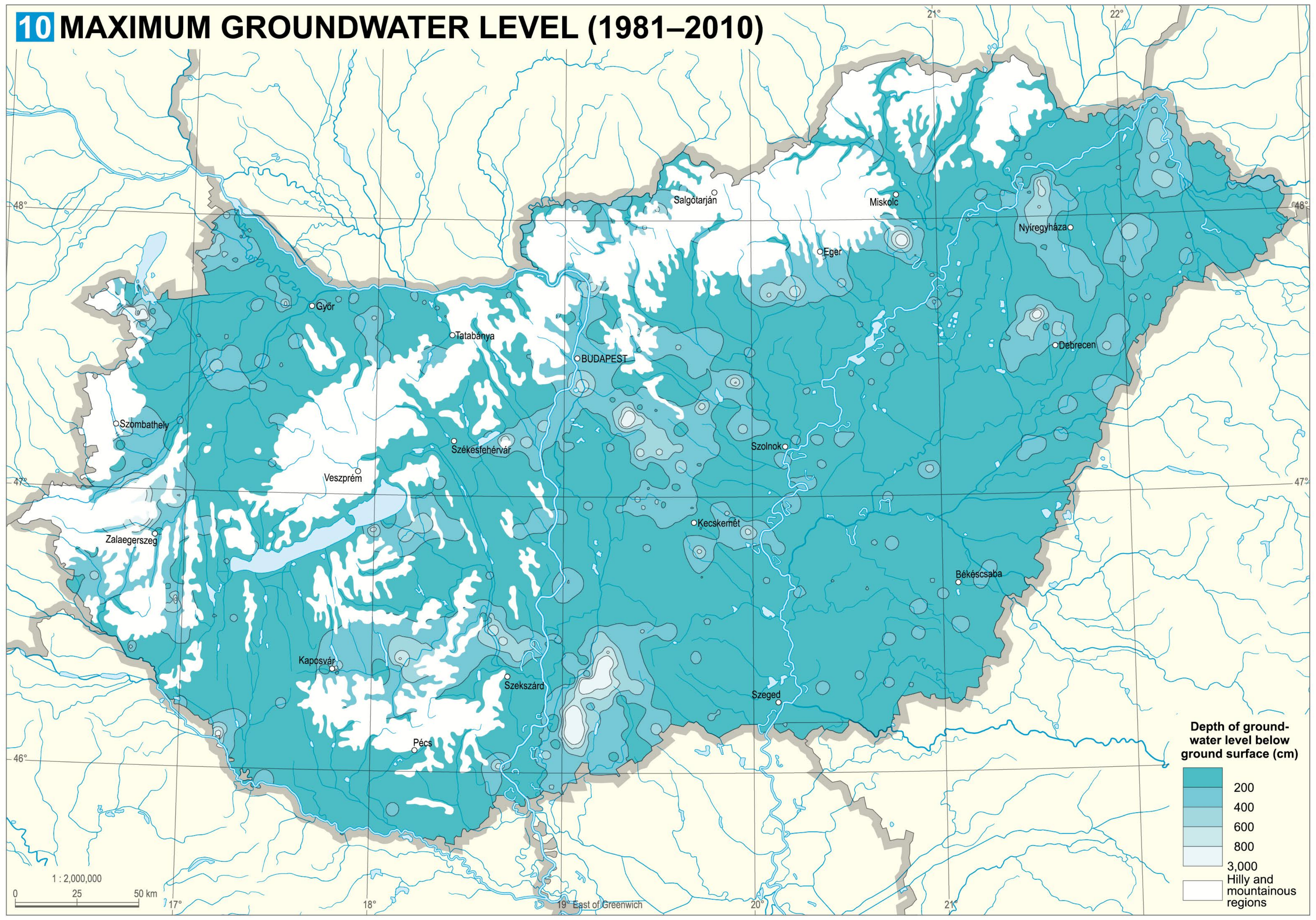
18 *In the Alföld, one of the types of dug wells is the shadoof, which is also a typical landscape element*

In the first half of the 1950s, a database was developed by the Geological Institute of Hungary (MÁFI) that comprised of water levels measured in nearly 770,000 wells that provided daily water supply. Data was collected during groundwater level surveys con-

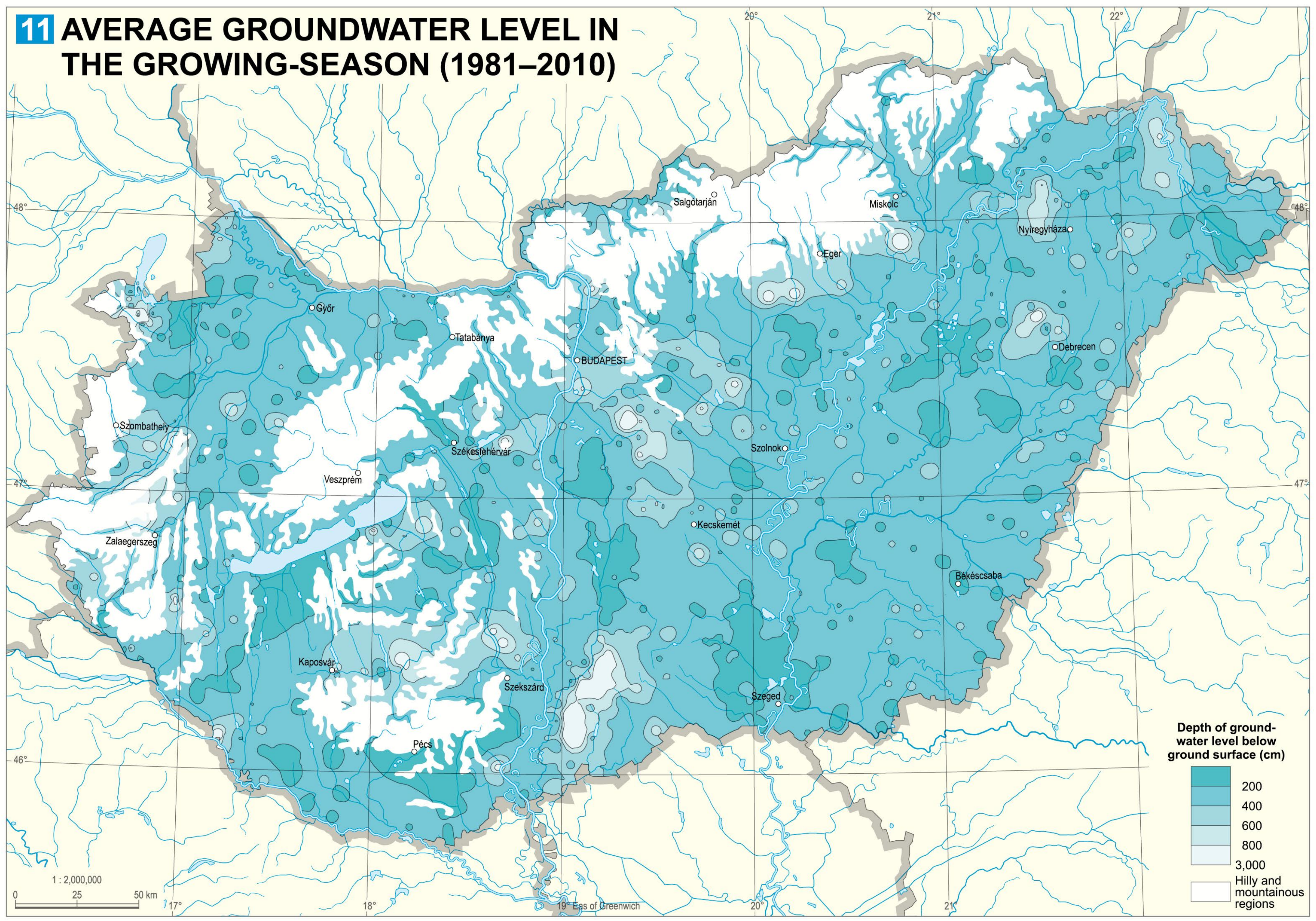
9 MINIMUM GROUNDWATER LEVEL (1981–2010)



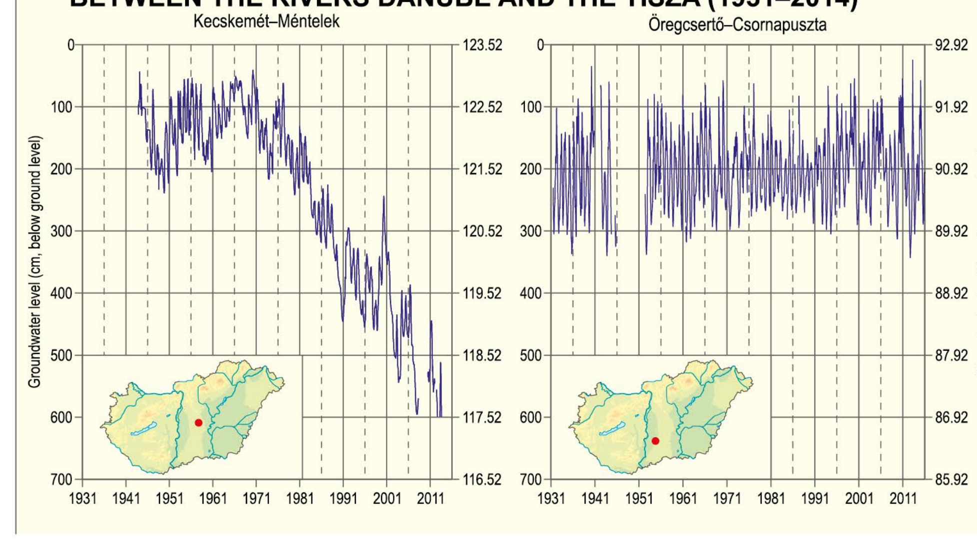
10 MAXIMUM GROUNDWATER LEVEL (1981–2010)



11 AVERAGE GROUNDWATER LEVEL IN THE GROWING-SEASON (1981–2010)



12 HYDROGRAPH REGIME OF TWO GROUNDWATER BOREHOLES BETWEEN THE RIVERS DANUBE AND THE TISZA (1931–2014)



ducted by the Water Resources Research Institute (VITUKI) whereby detailed knowledge on groundwater flow patterns in the Alföld were observed as well as monitored to ascertain change in water levels. The researchers confirmed that the location of groundwater table usually follows the surface terrain of larger lowland areas, and the groundwater level is primarily dependent on the distribution of precipitation over time. The highest groundwater levels are measured during spring and early summer seasons, while the lowest in autumn. The variability within a year is inversely proportional to groundwater table depth; in case of the groundwater table being located deeper, the effects on the ground surface will be noticed earlier. With regard to land use, both too high and too low groundwater level may have adverse effects on surface water patterns. High groundwater levels can cause overflow of excess waters 19, furthermore the persistent saturation of the root zone can limit plant development in agricultural areas; however, if the groundwater is located at great depth (up to 12–20 m), then most groundwater resources become inaccessible to most plants 9 10 11.

19 *Excess water inundation at Kaba*

The changes in groundwater levels are influenced by the annual fluctuations of climatic events, mostly precipitation, but partly also by human activity. The result was mainly due to the decrease of the groundwater level in the highest areas the Danube–Tisza Midland from the 1980s to the mid-1990s. This occurred mainly in the north and southwest of the ridge, which reached 4 to 8 m in certain districts, partially due to the drying up of some groundwater level monitoring wells and a significant part of existing drinking water wells. On the lower areas of the ridge a much smaller (1.5 to 2 m) and much more spatially diverse decrease occurred, while there was no significant change in the peripheral regions – mainly on the level of the Danube and the Tisza valleys 12. The water shortages in the water balance of the Danube–Tisza Midland are further increased by water withdrawal for irrigation.

Looking at the groundwater resources in Hungary, it can be concluded that groundwater in the Alföld is characterized by complex flow systems. Further to the perimeter fed areas, the Nyírség and the Danube–Tisza Midland are also infiltration areas, from where water flows along the regional routes to landscape boundaries and to valleys of the Danube and the Tisza. In the Tiszántúl region, where clay deposits are located on the surface, groundwater is under pressure. In the second half of the 1950s, measured water levels were mostly recorded between 2 to 4 m, elsewhere 4 to 10 m, and below 10 m in some cases. Later, due to the large-scale farming, rice cultivation and irrigation, the groundwater level of the major parts of Nagykunság, Hortobágy and Körös–Maros Midland temporarily increased, and the subsequent transformation of the structure of agriculture after 1990 led to a decrease in groundwater levels.

The Danube–Tisza Midland is typically a dry, water scarce area with no natural, permanent surface watercourse. The main source of water supply is precipitation, which is supplemented by water from deeper layers from purified industrial and communal sewage, water from the Danube and the Tisza for irrigation and water replenishment. In the Holocene–Pleistocene pebble and sandy formations there are no coherent watertight and water holding layers, therefore the area is characterized by complex flow systems; the water infiltrating in the highest areas of the ridge moves towards the lower peripheral areas. Other characteristics of the landscape are more inundations during persistent rainfall; areas previously covered with water become inundated once more though they dry out again during drier periods.

Under the northwest–southeast areas of the Mezőföld, the ridges of which are fragmented with river valleys, the depth of the groundwater is usually at significant depth (4 to 6 m in the south, and close to 10 m in the north), moreover the depths at the northwestern hilly areas are greater than 10 m. Closest to the surface – sometimes on the surface – the groundwater is present in the Sárrét area and in the Sárvíz as well as Sió valley.

The deep basin of Kisalföld is filled with loose river bed sediments, gravel and sand, with watertight layers, clayey and loess cover layers occur only in smaller areas. The groundwater reservoir of the basin is also fed from the permeable areas (Sopron and Kőszeg Mountains, Bakony, Vértes and Parndorf Plateau) towards the interior by subsurface waters. The groundwater is 4 to 6 m in the perimeter areas, 2 to 4 m in the basin – due to the favourable replenishment conditions – and in some zones, as in the Hanság area it is close to the surface, with a depth of 1 to 2 m.

The groundwater is located at significant depth (6 to 10 m) at the North Hungarian Range, made up of clayey, sandy terrains with deep valleys, and at the Transdanubian Hills, made up of clay and loess. There is usually no possibility for the formation of a coherent groundwater table: the water occasionally stored in separate layers above each other flows towards the valleys and often nourishes groundwater sources. In spite of this, the groundwater reserves of the mountain range basins are usually modest, more significant resources can only be found in the wider, often terraced valleys of larger rivers, at a depth of 2 to 4 m. In Transdanubia, the wider, terraced, filled plains store larger quantities of groundwater that move according to the slope direction.

Deep groundwaters

Deep groundwater is porous water located in ground water bodies that are deeper than 20 m or covered with a surface waterproof layer. The good water-bearing, water holding formations are the coarse-grained, sandy, pebbly, sandstone layers of sediment pools. These water-bearing layers are found in more than three quarters of the country's territory, providing drinking waters supply opportunities everywhere. However, as a result of extraction from deep groundwaters since the 1970s, water levels have been steadily declining. In layers providing adequate quality drinking water, the levels dropped an average of 5 to 10 m, and in the vicinity of larger waterworks and in deeper geothermal water storing formations the descent has reached more than 10 m. Moreover, the layer pressure that allows water to be extracted without pumping has been significantly reduced. The decline in water extraction at the beginning of the 1990s was also reflected in the changes of water levels, the descent slowed down, and in some instances an increase was observed.

The deep groundwaters that break to the surface spontaneously due to drilling are called artesian waters. In drilling such wells in Hungary, Vilmos Zsigmondy (1821–1888) and Béla Zsigmondy (1848–1916) had leading roles (1867: Margit Island, 1870: Lipik, Alcsút, 1876: Félixfürdő, 1878: Budapest City Park (Városliget), 1880: Hódmezővásárhely – the first open-air artesian well in the Alföld for public use).

Karstic water

An important type of groundwater reservoir formations is karstic rocks, which are found in half of the mountainous areas; they represent about one fifth of Hungary. These calcareous marine sediments – limestones, dolomites – formed predominantly during the middle ages of the geological history have quite good water-bearing capacity along the fractures, fissures and cavities created through the karstification process. Precipitation in karstic rocks that reaches the surface usually results in direct and rapid infiltration, so karst water recharge is generally very good. Karstic formations are covered in many mountainous areas by poor water-bearing formations, and at upland edges karst water reservoirs can be covered in large thickness by debris of sedimentation pools, which are usually watertight. In the karstic formations found in the mountain ranges and under the basins, there are thermal waters, some of which emerge to the surface in thermal springs (Hévíz, Budapest, Eger, etc.) 13 20 21.

The sources at Buda emerge at the juncture of the Danube and Buda Mountains, along a narrow structural fracture. The hot springs between the Gellért and József Hills on the sections close to the Danube 21, the warm springs can be found on the flood plain of the Danube River, which stretches to the Csillaghegy part of the city. Between the Erzsébet and the Szabad-

20 *Fed by thermal springs, Lake Hévíz is also famous for its healing power*

21 *The Buda thermal water, Molnár János Cave*

ság Bridges there are at least a dozen sources beneath the water level in the Danube bed.

In Hungary, karstic water levels were significantly influenced by human intervention, primarily mining activities. Water abstractions ensuring the safety of coal and bauxite mines threatened by the intrusion of karstic water have become more and more intense in the Transdanubian Range since the 1950s, thus the originally natural water regime of the karstic reservoir was fundamentally transformed. Due to the recent mine openings and to water extractions which assist production, the regional pressure drop led to flow reduction of once significant streams, and even to the drying up of others. The impact of human intervention can thus be divided into two parts: the drop of the karstic water levels (1950–1990) and the regeneration of the karstic water (1993–). The replenishment of karstic aquifers resulted in the rise of the karstic water levels in some regions. However, this caused problems, as during the period when karstic water level decreased, the regions with springs and previously high water levels were built-in; in buildings found in this area – often residential houses – streams have reappeared and infiltrated into cellars, garages and backyards. The settlements affected by this phenomenon include Tata, Dunaalmás, Esztergom, Vértesszőlős, Bodajk, Fehérvárcsurgó, Csór, Inota, Öskü, Pétfürdő, Pápa, Tapolca, Veszprém and Hévíz.

Mineral, medicinal and thermal waters

Hungary is exceptionally rich in mineral waters, *especially* thermal waters, which is primarily due to the geological and geophysical properties of the Carpathian Basin: the thin Earth's crust and the high heat flow. Subsequently, we have devoted pages 24–26 to these great *components* of our water resources in the geology chapter of our atlas.

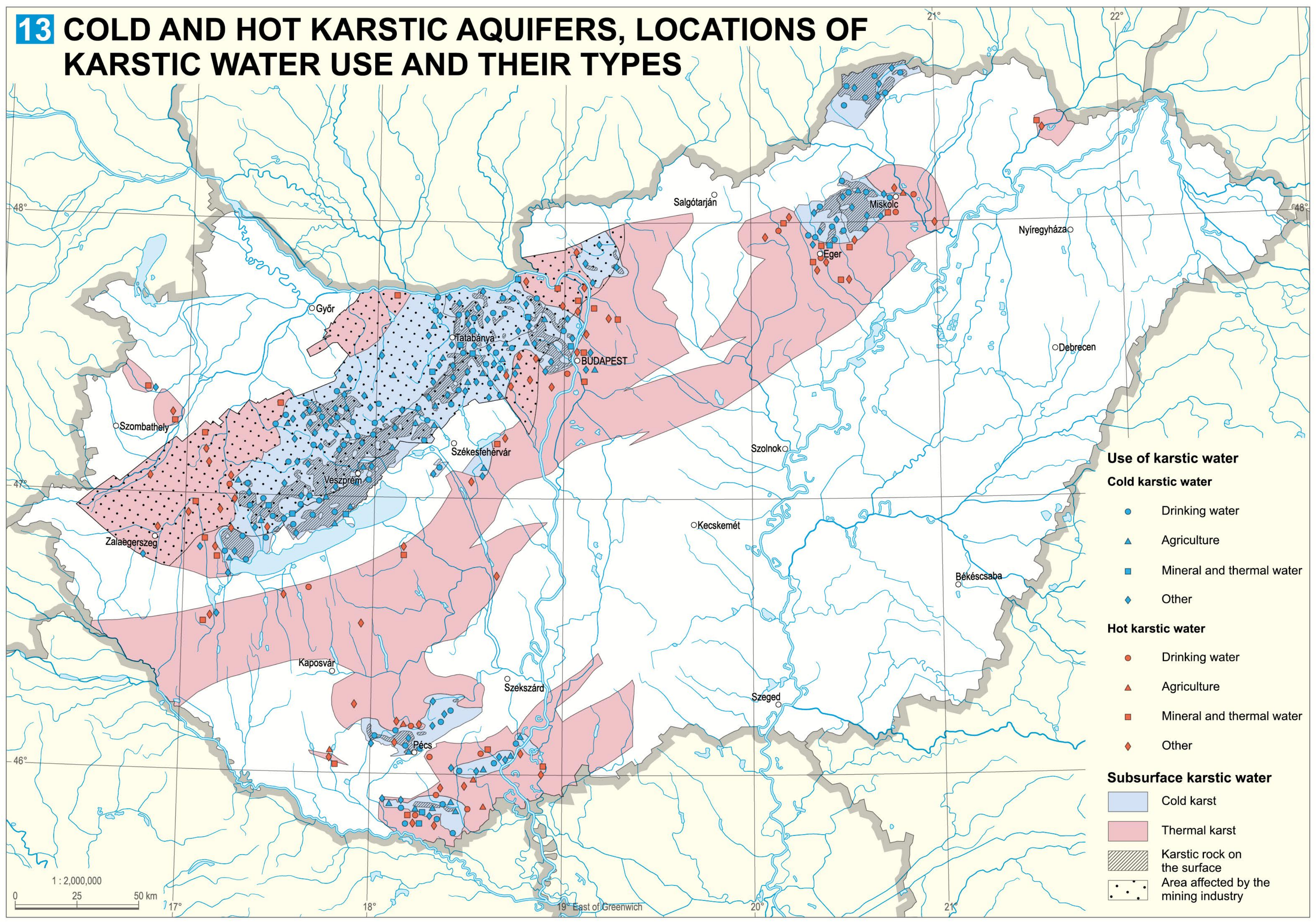
The Hydrological Monitoring Network

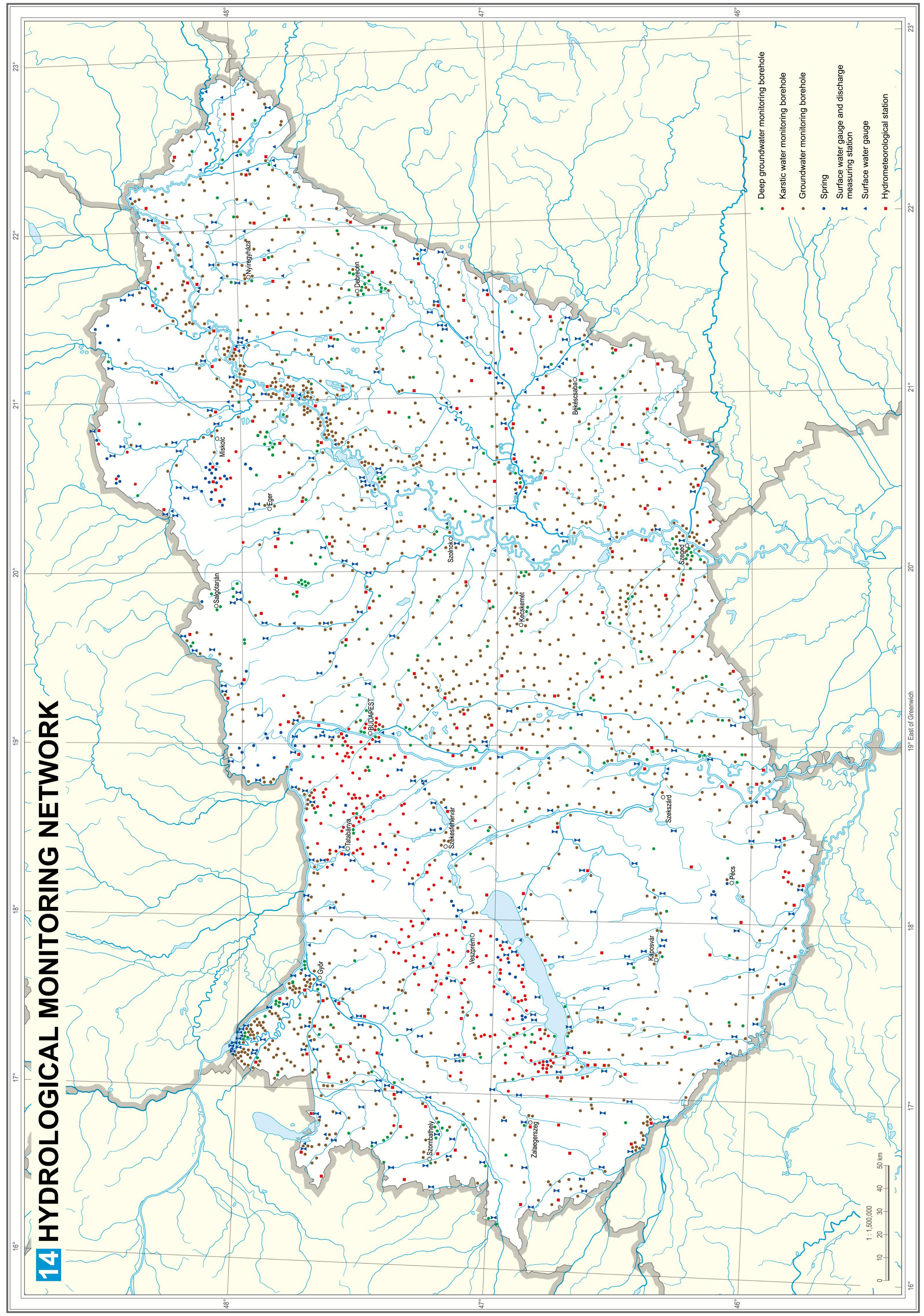
The hydrological monitoring network refers to the station network capable of continuously monitoring the characteristics of water (quantity and quality). There is an extensive network of surface, subsurface, groundwater and hydrometeorological stations in the country 14. Regular hydrological baseline data is collected; mostly day-to-day or independent, yet occasional monitoring activities are carried out at the stations, namely the surveying and continuous recording of natural and artificial water features. There are two main types of hydrological observation networks: regional observation networks that continuously record the continually distributed and changing factors on the Earth's surface (precipitation, air temperature, etc.) and a monitoring network of waters (also known as line network for surface waters).

In Hungary, under the management of the National Water Directorate, the 12 geographically competent Water Management Directorates are responsible for the operation, maintenance, upgrading and development of the current 8,000 stations, as well as for the collection and evaluation of the hydrographical data that characterize the hydrological features. In the frame of hydrographic monitoring, the following data are collected: water levels, water temperature, water velocity, water flow, ice conditions, sedimentation conditions, groundwater, water reservoirs, springs, furthermore hydrometeorological values – rainfall, snow, water equivalent, air and water temperature, relative humidity, soil moisture – are also measured.

Hydrographic detections and measurements are carried out at core stations providing nationwide and regional perception, as well as at operation management stations and research stations. Data measured and detected on the core network are processed in accordance with uniform principles. There are about 350 surface core stations and more than 1,700 operating stations with continuous water detection, and out of these, more than 410 stations with remote sensing capabilities. Besides these, there are more than 800 additional water monitoring stations for flood prediction and climatic change research. There is continuous detection of groundwater levels at more than 550 core stations and more than 160 service stations, out of these only 4 have remote sensing capabilities. The number of water flow measuring stations currently exceeds 380, and the number of continuous water temperature measuring stations is around 150. In addition, the Hydrographic Service maintains about 500 hydro-meteorological stations in the country where the precipitation is continuously measured.

13 COLD AND HOT KARSTIC AQUIFERS, LOCATIONS OF KARSTIC WATER USE AND THEIR TYPES





14 HYDROLOGICAL MONITORING NETWORK

VI.

VI.

MNA Natural Environment

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  Faculty of Science and Technology, Institute of Earth Sciences (Természettudományi és Technológiai Kar, Földtudományi Intézet)
University of Miskolc (Miskolci Egyetem, ME)
  Faculty of Earth Science and Engineering, Institute of Geography and Geoinformatics (Műszaki Földtudományi Kar, Földrajz-Geoinformatika Intézet)
University of Pécs (Pécsi Tudományegyetem)
  Faculty of Sciences, Institute of Geography and Earth Sciences (Természettudományi Kar, Földrajzi és Földtudományi Intézet)
University of Sopron (Soproni Egyetem, SoE)
  Faculty of Forestry, Institute of Botany and Nature Conservation (Erdőmérnöki Kar, Növénytani és Természetvédelmi Intézet)
  Faculty of Forestry, Institute of Forest Resources Management and Rural Development (Erdőmérnöki Kar, Erdővagyon-gazdálkodási és Vidékfejlesztési Intézet)
University of Szeged (Szegedi Tudományegyetem, SZTE)
  Faculty of Science and Informatics, Institute of Geography and Geology (Természettudományi és Informatikai Kar, Földrajzi és Földtudományi Intézet)