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Groundwater – an invisible natural resource[***]

Abstract

In Hungary, both the supply for drinking water, irrigation water and balneological water demand are satisfied mostly from groundwater. In our study, we present four areas where lawmakers will have to answer questions urgently in the future.
The re-injection of thermal water used for energy purposes, the obligation to notify and authorize wells drilled into groundwater aquifers, and the growing need for irrigation water from the agricultural sector, as well as the regulations of cross-border water bodies, are all urgently need a solution to ensure sustainability.
In this complex work, legislation can effectively help professionals to meet our goals.
Keywords: water law, groundwater, water management, water protection

1. Introduction

Hungary is of great importance to underground water resources that is the invisible part of the hydrological cycle.[1] Most of Hungary's drinking water supply comes from the country's groundwater systems.[2] Hungary is well known for its mineral-, medicinal- and thermal water resources, as well as its favorable geothermal conditions.[3] The increasing agricultural demand for water is also fulfilled by using groundwater. The professional responsibility of hydrogeologists is of high importance in utilizing the country's groundwater with respect to quantitative and qualitative aspects in a sustainable manner and preserving it in the long term.[4] In recent times, Hungary has had to face many new global or local, natural and social problems, whose adverse effects are unfortunately significant to groundwater. Present as well as

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[1] Szűcs 2017.
[2] Juhász 2002.
[3] Bobok & Tóth 2010.
[4] Hatvani et al. 2014.

future hydrogeologists will have to respond effectively to new types of professional challenges through innovative solutions based on intensive research.[5]

The introduction of the National Water Science Program[6], which is accepted and supported by the Hungarian Academy of Sciences, can play a significant role in the realization of these ideas. In the present study, the authors wish to draw attention to groundwater related topics, where Hungary faces serious challenges.[7] In these areas, the modification or strengthening of legislation could in many ways help to protect our underground water resources which can be considered as an invisible natural resource. The topics covered in this study concern the issue of re-injection of energy-related thermal waters, the supply of agricultural water needs from groundwater, the risk of establishing wells without permits or unannounced, as well as in case of groundwater production, problems of developing protection areas/zones in open karstic environment and in areas concerning administrative borders.

2. Sustainable thermal water utilization

The production and utilization of hot water above 30 °C, i.e. thermal waters[8] is of paramount importance. The amount of domestic heat production reaches 100 million cubic meters per year. Half of this amount, circa 50 million m^3 of water per year, is utilized in balneological way, in bathing areas. The re-injection of these waters utilized in baths and spas cannot be carried out because of bacteriology or of other reasons. That is why it is especially important that the other approx. 50 million m^3 of thermal water production, which is for energy, needs to be re-injected into the subsurface because of sustainability reasons.[9] Since thermal systems have limited natural replenishment, therefore, due to uncontrolled overproduction, there may be serious negative impacts that can seriously endanger our entire groundwater source, which is at the same time a source of our drinking water, world famous mineral and medicinal waters.[10]

Based on the regional distribution of the thermal water storage systems in Hungary, it can be concluded that the geothermal conditions of Hungary are outstanding. In the most favored area, at the Southern Great Plain, practically for all settlements, the thermal water production and heat utilization are geologically possible from the upper-pannonian sand layers. In this region, however, it is clear that the production of our thermal water resources, in many places exceeds the sustainable level. Consequently, in these areas, a continuous decrease of water levels can be registered. Therefore it is very important in the case of water extraction for energy purposes, the reinjection is now statutory required. The re-injection of thermal water is basically

[5] Hajnal 2007.
[6] MTA 2018.
[7] Palcsu et al. 2017.
[8] Mádl-Szőnyi et al. 2015.
[9] Székely 2010.
[10] Buday et al., 2015.

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necessary for two reasons: to counterbalance the aquifer pressure (sustainability) and to avoid contamination of the surface recipients (water quality protection).

The article about water reinjection in the Act LVII of 1995 on water management was changed in 2013 most likely due to the pressure from the agricultural sector, resultingin the abolishment rather than the restoration of the reinjection obligation in general. Thus, since 10 June 2013 it is the water authority's sphere of action to require re-injection upon authorization, for instance when the used water cannot be accommodated to a surface receiver because of lack of receiver or part of the underground aquifer lost large volumes of water. Under the present regulation, the practice shows that the water authority cannot issue a sufficient number of obligations for thermal water re-injection. Following the amendment of the law, a milder regulation was also amended, which entered into force on 31 December 2013. According to these modifications, the emission limit value for the salt content of waste water/used water (which is subject to a fine) was raised and the multiplication parameter for geothermal water utilization resource fee (g multiplier, Decree 43/1999 (XII.6) was reduced from 7.5 to 2.0. These modifications show that the present economic regulation does not encourage reinjection.

The revised National River Basin Management Plan (VGT2) has identified the thermal water abstractions as significant loads that have an impact on the quantitative status of groundwater. VGT2 notes that the use of thermal water for energy purposes in our country can be usually associated with wastefulness. Reduction of loads can be achieved in several ways: partly by regulate water abstraction, partly by reinjection of used thermal-water for energy purposes, or mostly by using more efficient technologies (such as multi-stage or cascade system, recirculation).

According to the VGT2 documentation, following social consultations, reinjection of 40% of the thermal water used for energy purposes is expected by 2021, taking into account EU subsidies as well. Based on the current legal situation and the practical handling of the issue, achieving this target value is not realistic. As long-term planning and thermal water management are based on the obtainable number of data, the data service related to thermal water wells (production data, SWL and water level report) and control should be expanded and tightened. It is imperative to expand the monitoring network for porous thermal waters.

Protecting our subsurface water resources should be given higher priority than what is currently established.[11] From the point of water management view, it is unacceptable that from the approx. 50 million m^3 thermal water production for energy purposes, only approx. 5-6 million m^3 are injected back to the aquifers. A very good example of domestic sustainable geothermal energy utilization is the large-scale investment in Miskolc, Hungary, resulting in the largest geothermal power plant in Central Europe with about 60 MW of heating capacity. In the Kistokaj and Mályi region, 2 production and 3 re-injection wells were drilled. After the cascade heat utilization, the total amount of thermal water produced is reinjected into the deep karstic system so as to keeping the energy conditions.

[11] Szanyi & Kovács 2010.

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In the light of all this, the solutions shown in this paper could be presented to the economy, keeping the use of agricultural water, greenhouse, vegetable and fruit production, since the goal is to keep thousands of jobs and to reduce carbon dioxide emissions by using thermal energy as well as the EU-backed usage of renewable energy.[12]

A legal solution to the problem may be the modification of the Act of Water Management in such a way, that the partial or total rejection against other surface receivers should be preferred. Another change may be that the current g multiplier equaling 2 should be raised to at least 4.0-4.5 (above the multiplier of balneological use), to stimulate farmers to partially reinject or even those users who heat buildings with thermal water without any reinjection.

The technical ground of solutions can be to support research development programs that allow the technological improvement of reinjection methods. In general, the usual reason for the lack of rejection of thermal water is, that it is not feasible. The reality is that water rejection is a routine technology that is widely used in the oil industry. It is necessary to develop this technology so that reinjection can be performed more reliably and with less expensive operation into the upper Pannonian sandy thermal aquifer layers in Hungary.

The re-injection into sandstone is a problem in many European countries (e.g. Slovenia, Denmark, the Netherlands and Poland), hampering the development of geothermal energy utilization. The demand for efficient, and modern technologies for geothermal energy across the EU is already high.

A third solution proposal might be, that the government would declare the solution to this problem as strategic, and the state will also help to resolve the situation on the merits. The most important governmental help would be for thermal water using farmers to finance reinjection wells from state funding. This solution can also be based on the fact that the Rural Development Program of 2014-2020 supports the creation of reinjection wells in principles. Experts estimate that in our country there are approx. 180 active thermal wells in the agricultural sector where re-injection is not yet solved. Developing a reinjection well costs about HUF100 million. If the state were able to support the construction of a reinjection well as well as the production well under a complex aid scheme, the cost would be approx. HUF18-20 billion. This investment would worth the price in every respect, since the protection of our unparalleled thermal water reserves could be reassured in Hungary.[13]

3. The question of the wells to be established without authorization and notification procedure

Groundwater plays a pivotal role in Hungary. Drinking water is supplied almost entirely from underground water resources. Our world-famous mineral-, medicinal- and thermal waters are also being produced from groundwater. We can regard groundwater in rocks and cracks as one of the most valuable natural resource.

[12] Petitta et al. 2018.
[13] Szűcs et al. 2015b.

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However, the groundwater system, which is invisible to the human is very complex below the territory of the country.[14] This highly important natural system is very complex and sensitive. In order to understand the main legalities, it is essential to know the basic hydrogeological parameters, the groundwater flow systems along with water flow, mass and heat transport processes and its interactions with each other. Although processes along the flow systems take place at a very low speed, any interference with groundwater never remains local, but in years, decades or even centuries, the effects will occur in larger space as a result of hydraulic continuity.

In Hungary, when the river basin management plan was drawn up in 2010, 185 groundwater bodies were designated. The number of shallow porous water bodies is fifty-five, while the number of shallow mountainous water bodies is twenty-two. That is, there are 77 shallow groundwater bodies in Hungary, which would be affected by accepted deregulation in any way.[15] Due to the proposed deregulation, with the depth of 80 meters, a significant part of the 48 porous water bodies can be negatively affected. This means that over half of the groundwater bodies will certainly be affected by the proposed regulation in some way. The adaptation of the proposed law is to establish a regulation that does not require authorization or notification procedures for wells up to a depth of 80 m. If this were to happen, no set-up information would be available for the shallow groundwater that are above than 80 meters or the operation and impact of the wells. Expected negative impacts may affect the relevant groundwater resources in quantitative and qualitative terms. It would render reliable river basin management planning impossible and abolish groundwater resource management. It would endanger the world-famous drinking water of our country today.

3.1. Expected quantitative aspects

In the world's water supply, groundwater has taken the lead against surface water. 75% of drinking water supply in Europe, while more than 95% of the water in Hungary comes from groundwater. Although the daily capacity of drinking water utilities in Hungary is 4.5 million m^3, the annual volume of drinking water produced is only approx. 700 million m^3. In addition to drinking water, our groundwater resources, including our mineral and medicinal waters, as well as thermal waters, were even more appreciated due to the well-known balneological and energy related water utilization. The volume of domestic thermal water production can be up to 100 million m^3 per year, according to official data and estimates. The majority of the 700 million m^3 drinking water production per year is made up of wells whose filtered sections lie below the surface at depths between 50 and 150 meters. Apart from known and registered water abstractions, sadly, hundreds of illegally drilled wells are burdening the groundwater resources in Hungary today. According to some estimates, the number of illegal wells can even reach the number of one million. These existing illegal wells are not deeper than 50-60 meters.

[14] Szűcs et al. 2015a.
[15] Szilágyi et al. 2017.

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Unfortunately, the current situation also poses serious problems, as the water production of these wells can reach up to 100 million m^3 per year. This quantity already seriously threatens sustainable groundwater management and planning in several areas.

In the light of all this, the depth of 80 m for a well in the adopted law is professionally unacceptable, as this would mean a further uncontrolled use of the so-called protected waterworks layers in the country. Due to the basic rules of groundwater flow systems, water resources at different depths are highly sensitive and are in a complex relation to each other. As a result of the proposed law, not only the local high-quality and high-quality drinking water supplies can be endangered, but in the long run, the quantitative conditions of our world-famous mineral, medicinal and thermal water supplies could be damaged too. Excessive and uncontrolled water abstraction near the surface will adversely affect the natural recharging conditions of deeper aquifer layers. It would be impossible to make local, intermediary or regional water balances, as no information would be available on the newly drilled wells, their water production data as a result of the lack of notification and authorization obligation. That is, as a result of the planned regulation, an unpredictable number of new wells can be created, overusing the current aquifer (Figure no. 1). The new wells, and very large percentage of the water production from the new wells can be entirely excluded from the regulatory horizons of the water authority, river basin management planning and sustainable water management.

The uncontrolled abstractions can manifest as significant (up to 0.5-1.0 m) drop in water levels, which could lead to a damage to the groundwater-dependent ecosystems (FAVÖKO). However, the predictable, large-scale country-wide groundwater level decrease cannot only affect natural vegetation, but can also increase the irrigation demand of arable crops. To alleviate this process, even more uncontrolled wells would be drilled, thus undermining the quantity of groundwater in kind of a negative spiral.

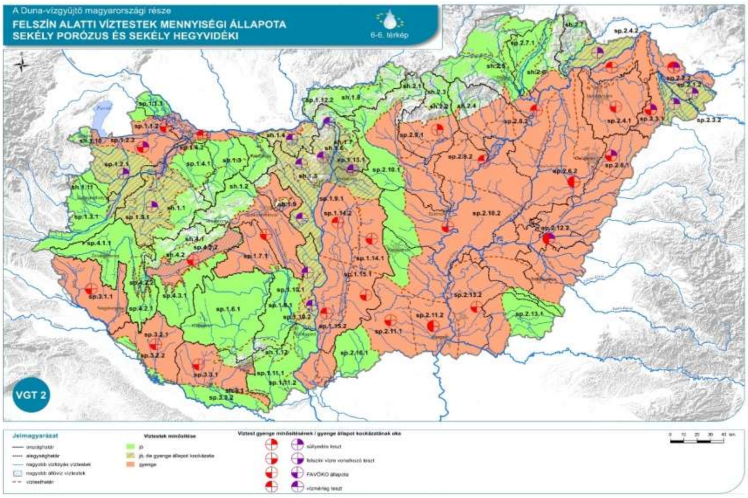

Figure no. 1
Quantitative status of porous shallow and mountainous shallow groundwater bodies

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3.2. Expected qualitative aspects

The chemical status assessment according to the national river basin management plan examines whether the pollutant has penetrated the groundwater and, if so to what extent. A significant proportion of their groundwater bodies are vulnerable, which means that due to their geological structure, contamination from the surface can enter the groundwater in a short period of time, where they can be mixed and groundwater flows may even help contaminate a whole body of water resulting in a poor chemical status. The presence of contaminants in the aquifers supplying drinking water can directly jeopardize human health, thus water basins in the water bodies will be given a particular attention during the state assessment.

Due to the lack of license and reporting obligation and the lack of control, the high risk of contamination of our current clean and protected aquifers or the unintended linking of already contaminated and non-contaminated water bodies, which will further undermine the situation in many areas in our country. The greatest danger is the lack of know-how of professional planning and drilling procedures. In the absence of plans, permits and training, drilling with amateurs would end up in a well without any technical protection, such posing an enormous risk to groundwater contamination. Badly formed and cemented boreholes can serve as almost vertical gravitational dropping wells to different types of surface contaminants. Then, through the groundwater flows, the spread of water-soluble chemicals in a horizontal or even in a vertical direction is unstoppable. It is well known that the removal of groundwater pollution can be a very expensive process, which can take years. Many times it is not even possible at all. Considering all of the above, it can be stated that such a degree of risk cannot be taken for the protection of our groundwater resources. Another danger could be the creation of an unauthorized well in the surface protection areas of a drinking well, which may have an adverse effect on the officially licensed water production, beyond water quality problems. The thought of protected water sources is seriously at risk, since the wells with no permit and no obligation pose an unseen and uncontrollable ways for contaminants to easily migrate into the subsurface.[16]

In Hungary, a significant part of surface water and groundwater is already contaminated to such an extent that it can be utilized only as potable water or even as irrigation water only after a very expensive water treatment and cleaning process. The above-mentioned illegal and poorly constructed and poorly-maintained wells have so far played a significant role in the current not good state (Figure no. 2). It is not a coincidence that for many years now, the domestic hydrogeologist society has been urging the authorities to take actions against illegal, therefore uncontrollable and typically improper drilling.

[16] Zákányi & Szűcs 2014.

doi: 10.21029/JAEL.2019.26.299

Naturally, it is necessary to deal with the need for new water supplies from the society. In a well-functioning and information-driven system, water management professionals will do their utmost to satisfy the right water needs. To this end, the social organizations' and decision-makers' good intentions are needed as well as data and information about our water resources, and the knowledge of the laws of nature. In terms of water resources, we can only make decisions with responsibility after this. In the institutional network and the commission system of the Hungarian Academy of Sciences, there are also a lot of excellent water experts who are eager to solve professional issues related to the satisfaction of water needs.

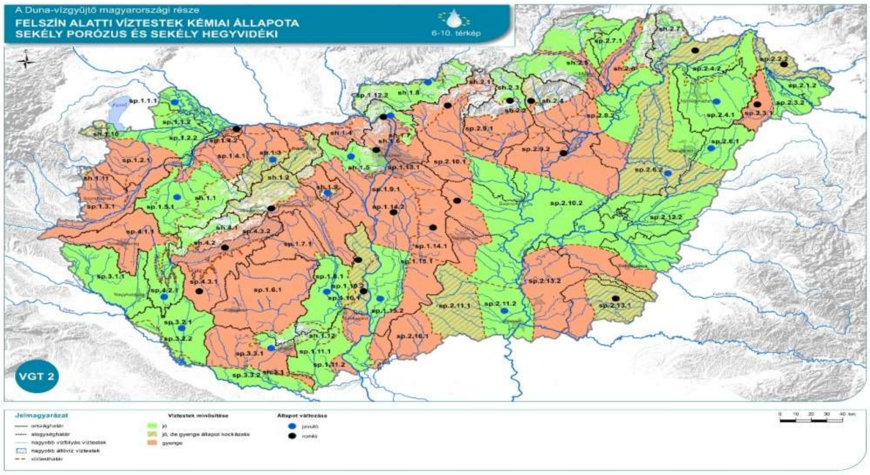

Figure no. 2
Qualitative status of porous shallow and mountainous shallow groundwater bodies

4. To meet the agricultural needs of water from underground water resources

Nobody disputes the importance of satisfying the demands of agricultural water needs. This is a very important national economic interest. Firstly, we need to increase the size of irrigated land in the future in order to increase average yields. The demand for irrigation water can be achieved mainly from surface waters. Of course, groundwater resources can also be considered in terms of water demand. Based on careful analyses, annually about 100 million m^3 of groundwater will be used for irrigation later, which can fulfil the irrigation of approx. 45,000 hectares of agricultural land. However, it is important to mention, that with irrigation the goal of increasing crop yields can be achieved only by improving soil status in agricultural areas at the same time. Unfortunately, the current situation is quite worrying (Figure no. 3). In many places, our soils are in a bad condition and so compacted that irrigation in these areas would not be very effective.

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That is why, irrigated water would not go where it is intended under these bad infiltration conditions. So, for the sustainable utilization of our water resources it is important that the state of the agricultural soils in the future could significantly improve.

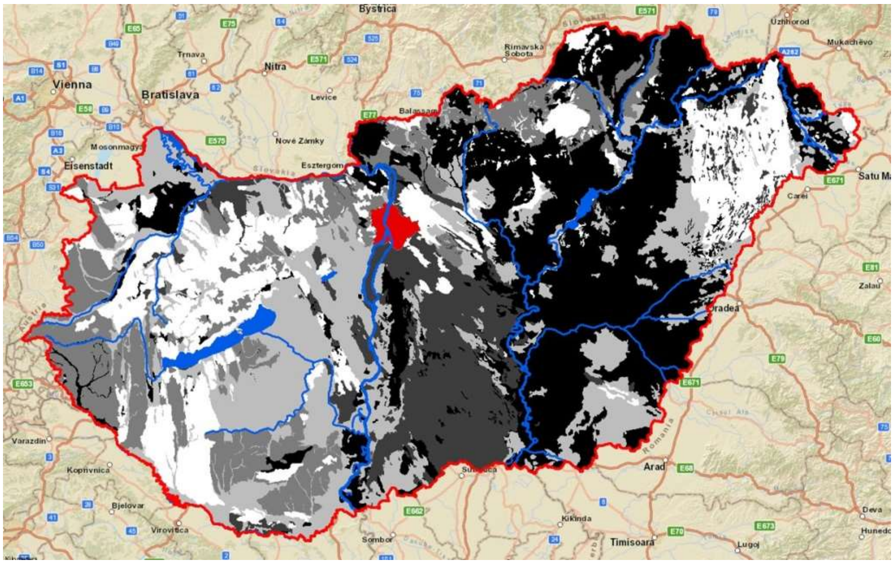

Figure no. 3
Soil compaction status based on the national soil degradation database

5. Problems with the formation of protective areas and zones

A significant part of the regulations and technical appendices that have been in place for 20 years, should be revised and modernized based on the extensive experience and feedback gathered so far. The experiences of the last two decades also showed that in some cases there were impossible and impracticable requirements because of some current regulations. Currently, more than half of the 1700 groundwater basins in Hungary are in a geological environment that are vulnerable to anthropogenic contamination. In addition to the groundwater bases, 19 surface water basins can be used for drinking water supply. Their protection and their protection at a higher level is served by the Drinking Water Protection Program. In 1995, the total of the 614 operating water bases and 75 distant water bases were incorporated in the Drinking Water Protection Program. From the state budget and KEOP sources, 43% of the public drinking water bases (83% of the vulnerable drinking water bases in operation) are being evaluated and the diagnostic study is in progress, covering almost 90% of the public drinking water supply (Figure no. 4). The status assessment of long-term drinking water bases has been completed, and 66 has been assigned by ministerial decree. There is a significant delay in issuing these resolutions.

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According to the records, more than half of the drinking water bases which are in a vulnerable geological environment do not have a legally enforceable protection area. There are significant number of water bases without decrees.[17]

In the National Water Strategy (in the Jenő Kvassay Plan), the following statements have been drafted regarding the national water protection: (a) To secure operating drinking water bases is still unfinished, the maintenance of the system of safety and its financing is uncertain/unsatisfactory even for perspective drinking water bases; (b) The designation of the drinking water basins of the capital city and the metropolitan area, which are mainly river bank filtered systems, are in progress as they are typically located in a built-up area, and the issuance of decrees are slowed down by the legal requirements for river bank filtered systems.

As described in the National Water Strategy, there are tasks to be implemented in the coming years (until 2021), but the requirements for available EU funds are impossible or the quantity of the support is insufficient. In these circumstances, it is recommended to move in three directions: to expand domestic – national – resources, apply economic regulation tools and increase the efficiency of subsidies. The most important tasks to be financed (partly) from domestic sources: (a) Eliminating the emergency situation in the Transdanubian Mountains due to the increase of karst water levels; (b) Securing water bases and compensating operations; (c) Water Utility Network Reconstructions; (d) Development and operation of a monitoring system.

VGT2 has revealed that the efficiency of water base protection is not sufficient, 68% of the water bases have no designated protective area/zone and securing them is in huge delay. This is why it (VGT2) has aimed to speed up the designation of protective areas and making waterbase protection more efficient in the everyday life. For this purpose, the protection zones of drinking water bases and the rules for the designation of these zones have to be reviewed based on the experience gained since the introduction of Government Decree 123/1997 (VII.18.). The risk validation approach which was introduced in water security planning is also justified in the field of water protection. The results and experiences of the performed diagnostic work must be taken into account.

In the open karst area, there is a difficulty in designating a protective area or a zone in accordance with the regulations of the current governmental decree. Due to the structure of the aquifer, the internal and external protective zones determined by the access times involve a large area, and strict fulfillment with these requirements couldn't be often solved.

In the case of transboundary groundwater it often happens[18] that the protection zone, which was determined by models based on diagnosis, stretches across national borders.[19] The designation of protected areas can only be carried out in accordance with the Hungarian legal system, so in case of transboundary aquifers some international coordination would be needed that enforces such standards that are applicable across borders.

[17] National Water Strategy 2017.
[18] Szűcs et al. 2013.
[19] Szőcs et al. 2013.

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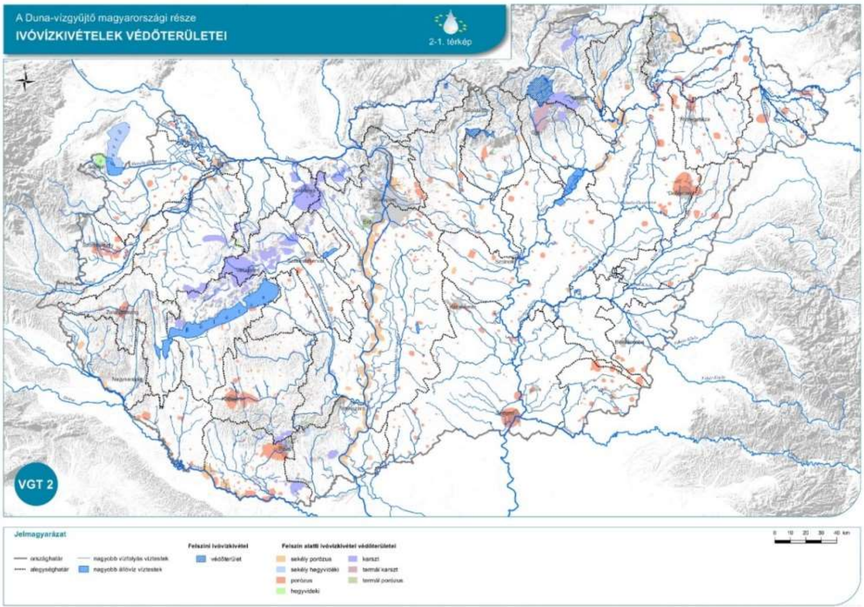

Figure no. 4
Protective zones of drinking water extractions

6. Conclusions

Our groundwater resources deserve special attention.[20] Our drinking-, mineral- and medicinal waters are coming from underground aquifers.[21] Part of the supply of the agricultural water demands can also be fulfilled from our groundwater resources.[22] Properly implemented water management is of utmost importance in sustainable utilizing our world-class water resources.[23] In this complex work, legislation has a very important role, as well-established legislation can effectively help to meet our objectives.

[20] Galloway 2010.
[21] Szűcs & Mikita 2016.
[22] Somlyódy 2011.
[23] Székely et al. 2015.

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Bibliography

1. Bobok E & Tóth A (2010) A geotermikus energia helyzete és perspektívái, *Magyar Tudomány* 171(8), pp. 926–936.
2. Buday T, Szűcs P, Kozák M, Püspöki Z, McIntosh R W, Bódi E, Bálint B & Bulátkó K (2015) Sustainability aspects of thermal water production in the region of Hajdúszoboszló-Debrecen, Hungary, *Environmental Earth Sciences* 74(12), pp. 7513-7521.
3. Galloway D L (2010) The Complex Future of Hydrogeology, *Hydrogeology Journal* 18(4), pp. 807–810, doi: 10.1007/s10040-010-0585-1.
4. Hajnal G (2007) *Városi hidrogeológia*, Akadémiai Kiadó, Budapest.
5. Hatvani I G, Magyar N, Zessner M, Kovács J & Blaschke A P (2014) The Water Framework Directive: Can more information be extracted from groundwater data? A case study of Seewinkel, Burgenland, eastern Austria, *Hydrogeology Journal* 22(4), pp. 779–794, doi: 10.1007/s10040-013-1093-x.
6. Juhász J (2002) *Hidrogeológia,* Akadémiai Kiadó, Budapest.
7. Mádl-Szőnyi J, Pulay E, Tóth Á & Bodor P (2015) Regional underpressure: a factor of uncertainty in the geothermal exploration of deep carbonates, Gödöllő Region, Hungary, *Environmental Earth Sciences* 74(12), pp. 7523-7538.
8. MTA (2018) Nemzeti Víztudományi Program, http://mta.hu/nemzeti-viztudomanyi-program [30.11.2018]
9. Palcsu L, Kompár L, Deák J, Szűcs P & Papp L (2017) Estimation of the natural groundwater recharge using tritium-peak and tritium/helium-3 dating techniques in Hungary, *Geochemical Journal* 51(5), pp. 439-448, doi:10.2343/geochemj.2.0488.
10. Petitta M, Bodo B, Cseko A, Del Bon A, Fernandez I, García Alibrandi C M, Garcia Padilla M, Hartai E, Hinsby K, Muller P, Mikita V, Szucs P & van der Keur P (2018): The KINDRA project: sharing and evaluating groundwater research and knowledge in Europe, *Acque Sotterranee - Italian Journal of Groundwater* 7(1), pp. 7-16, doi: 10.7343/as-2018-324.
11. Somlyódy L ed. (2011) *Köztestületi Stratégiai Programok. Magyarország vízgazdálkodása: helyzetkép és stratégiai feladatok,* MTA, Budapest.
12. Szanyi J & Kovács B (2010) Utilization of Geothermal Systems in South-East Hungary, *Geothermics,* 39(4), pp. 357-364, doi: 10.1016/j.geothermics.2010.09.004.
13. Székely F (2010) Hévizeink és hasznosításuk, *Magyar Tudomány* 171(12), pp. 1473-1485.
14. Székely F, Szűcs P, Zákányi B, Cserny T & Fejes Z (2015) Comparative analysis of pumping tests conducted in layered rhyolitic volcanic formations, *Journal of Hydrology* (520), pp. 180-185.
15. Szilágyi J E, Baranyai G & Szűcs P (2017) A felszín alatti vízkivételek liberalizálása az Alaptörvény és az európai uniós jog tükrében, *Hidrológiai Közlöny* 97(4), pp. 14-23.
16. Szőcs T, Rman N, Süveges M, Palcsu L, Tóth Gy & Lapanje A (2013) The application of isotope and chemical analyses in managing transboundary groundwater resources, *Applied Geochemistry* (32), pp. 95-107.

17. Szűcs P, Virag M, Zákányi B, Kompár L & Szántó J (2013) Investigation and Water Management Aspests of a Hungarian-Ukrainian Transboundary Aquifer, *Water resources* 40(4), pp. 462-468.
18. Szűcs P, Kompár L, Palcsu L & Deák J (2015a) Estimation of groundwater replenishment change at a Hungarian recharge area, *Carpathian Journal of Earth and Environmental Sciences* 10(4), pp. 227-246.
19. Szűcs P, Fejes Z, Zákányi B, Székely I, Madarász T, Kolencsikné Tóth A & Gombkötő I (2015b) Results of the WELLaHEAD Project connected to water and mining. Geothermal potential of the Tokaj-Mountains. Pilot test of passive acid mine drainage water management, *FOG – Freiberg Online Geology* (40), pp. 170-177.
20. Szűcs P & Mikita V (2016) Felszín alatti vízkészleteink és a hidrogeológiai kutatások helyzete hazánkban, *Hidrológiai Közlöny* 96(1), pp. 7-20.
21. Szűcs P (2017) Felszín alatti vizek – a hidrológiai ciklus láthatatlan része, *Magyar Tudomány* 178(10), pp. 1184-1197, doi: 10.1556/2065.178.2017.10.2
22. Zákányi B & Szűcs P (2014) Víznél sűrűbb, nem vizes fázisú szennyezőanyagok transzportfolyamatainak szimulációja felszín alatti közegben, *Földtani Közlöny* 144(1), pp. 63-70.

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doi: 10.21029/JAEL.2019.26.299