Some aspects of the „3E's" (Economics-Environment-Ethics) model for sustainable water usage in the transboundary Slovak and Aggtelek karst region based on some examples from the Bükk mountains

Technical University of Košice

PhD THESIS WORK

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Faculty of Mining, Ecology and Geotechnology

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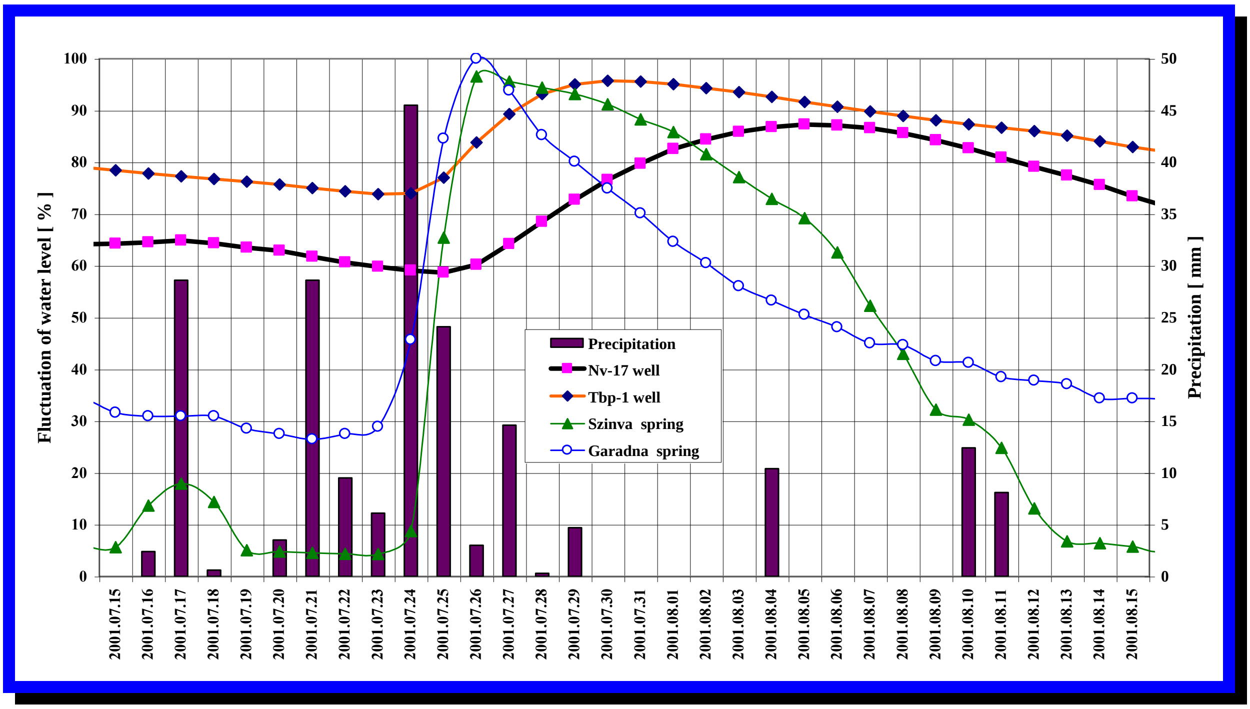


Supervisor: Prof. Ing. Tibor Sasvári, CSc.
Candidate: Dr. Univ. László Lénárt

Košice/Kassa, 2005.

The results of my work –
to my parents,
to my family
and to those
who had helped me;
with love and respect

(1951) – 1971 – 2005

Contents

Personal Motivation

I have been present at the ***Mining Engineering Faculty of the University of Miskolc*** since 1969 – first as geological engineer student, then geologist and teacher. With only one short period of absence I am still a teacher there.

When I started my studies at the University, I had entered into the activity of the ***Scientific Student Organization for Karsthydrology (cave explorers)***. Because of our location, we mainly visited and explored the caves of the ***Bükk Mountains***; we also composed scientific researches in the very same caves. During this period I had not only became impregnated with karst water physically but also mentally as I became devoted to ***karsthydrology, cave visitation, scientific cave exploration*** – all in all, to the wonderful world of the underground.

I had visited the biggest part of the over 1.000 caves of the Bükk. I had been in caves a few thousand times, in northern Hungary and abroad. Upon these occasions I had spent over 10.000 hours underground, engaged in one of the following caving activities: visiting, touring, exploring, photographing, giving training, mapping, conducting scientific research, monitoring and excavating new corridors. (Most of it happened in the ***Létrási-Vizes cave***, which is one of the mostly explored caves of Hungary.) I had lead for many years one of the oldest speleological associations of the country, the ***Marcel Loubens Cave Exploring Association***. For decades I have been part of Hungarian geologist, speleologist and caving organizations where I had a chance to actively work in the fields of caves and karstic regions. Two of the most important of these organizations are the ***Hungarian Speleological Society*** and the ***Hungarian Hydrological Society***.

Slowly my focus shifted to the monitoring and researching of karst water and I came to spend less and less time in caves. In 1992 I had founded the karst water monitoring network of the Bükk at the ***University of Miskolc***. In starting this work the support of the water works companies and authorities were very welcomed. The monitoring system works very well, its data are very useful for the examination of the karst water of the Bükk.

Since 1975, both in the Bükk and in other regions, I had introduced the characteristics and features of karst water systems and networks to hundreds of students, mostly in field trips and field work, within the frame of the University.

The nearest karstic region to the Bükk is the ***Aggtelek Karst***, which contains karstic caves. I had visited many times those caves as well, both for my own pleasure and for training and educating purposes, with my students and other interested youngsters. I had introduced the natural values of caves, the importance of nature and cave protection, the research and protection of karst water for many hundred people – students, other cavers and interested people. It is not a coincidence that I wrote my second thesis about an area of the ***Szalonna Karst***, the caves of the ***mount of Esztramos***.

I have a close connection to that area; to the inhabitants, their programs and caves, especially through the ***Gömör-Torna Festival, Jósvafő-Aggtelek Village Days***, in which I have been an active participant for over ten years.

In five studies I wrote as university student for the ***Scientific Student Organization***, in over 150 studies in the field of caves and karst (many of the studies with other authors), in over 100 private and university studies I had given proof of my professional work. I also wrote my ***degree paper*** (1975) and my ***doctor univ. thesis work*** (1983) in karstic-speleological theme, and my ***postgraduate thesis work*** in the karstic-speleological-environmental protection field (1990)

My first caving trip abroad was to ***Slovakia*** in 1974, to the ***Ardovská Cave, Silice Ice-cave*** and ***Nagy Shaft-cave***. My leaders and hosts were the cavers of Rimaszombat. I am still in touch with many of the researchers I have met there, and there are some studies written by them that I will use in this paper.

The year of 1985 was very important for me. We had visited a number of caves in Slovakia with the leadership of Sasvári Tibor. He is now my supervisor and after these 20 years I would like to say my thanks to him for his help as I couldn't do this earlier. During that trip we visited and made many good pictures of the following caves: ***Teplička Cave, Hrušovská Cave, Krasznahorska Cave, Jasovská Cave, Gombasecká Cave***. A little further away were the ***Bobačka Cave*** and the ***Ochtinska Aragonitová Cave***.

After this I have been many times at the ***Slovak Karst*** sometimes alone, sometimes with a group. My purpose was mainly to visit all the tourist caves – also to show it to my students -, but at times I just simply tried to get familiar with the area and engaged in hiking.

My professional work about karsthydrology seems to be fitting in very nicely with the current political, natural and economical challenges which resulted from Hungary's joining of the ***European Union*** and from the tasks of the ***Water Framework Directive 2000/60/EC***.

Based on the facts listed above, I think that my road – walked upon karsts and inside caves – had lead me straightly to the execution of the tasks presented in this paper.

1. Methods of research

1.1. Sustainable mineral resource management

Within the frame of the NATO Science Program, a conference titled the "Sustainable Mineral Resource Management in Karst Areas" had been held in Slovenia in the year 2000 ***[Shields and Šolar, 2000; Šolar et al., 2000]***.

The workshop portrayed the mining with three circles which overlapped each other ***[Barbic, 2000; Mihevc, 2000]***. The three circles meant the

- Economy
- Environment
- Society

Undoubtedly nowadays the water is one of the most important mineral resource on the Earth. Research, exploitation and protection of water should be done with the most serious care and with well thought-out water management.

The research of karst water is one of the special branches of water research. For this reason and for the topic of my paper I think it necessary to adapt some of the arguments presented at the workshop and to insert the logo here ***(Figure 1.1.1)***.

Fig. 1.1.1 The emblem of "Sustainable Mineral Resource Management in Karst Areas" [Šolar et al., (2000)]

1.2. The 3 E's definition of sustainable water resources management

The principles of the NATO Workshop mentioned above can be used very well in the process of karst water management. These directives also can be integrated into the Water Framework Directive, which is one of the most important regulations of the European Union.

The 2000/60/EC, the new Water Framework Directive ***[WFD 2000]***, adopted by the European Union in 2000 brings forth many new tasks and issues in the water management for the members and future members of the European Union ***[Somlyódy, 2002***; ***Holló, 2003; Simonffy, 2003a,b; Lénárt, 2004d; Lénárt and Tometz, 2004; Kullman et al., 2004]***.

There are many ways to examine the key issues of the WFD. I choose the 3E's approach: environment, economics and ethics. From this point of view I will evaluate the sustainability of karst water utilization. This approach is based on ***Barraque***'s work, a French researcher, whose paper was published in July of 2003 in Lisbon. In his work, ***[Barraque, 2003a,b]*** stated the following six issues as most important:

- Hydrographic districts
- Reaching the state of reference
- Economic analysis and cost recovery
- Public information and participation
- Dangerous substances
- Groundwater

Figure 1.2.1 displays the three dimensions of these major issues that ***Barraque*** finds most important**.** Therefore I will evaluate the sustainability of karst water management from the 3 E's point of view – **ethics, economics and environment** –, detailing some points in this work.

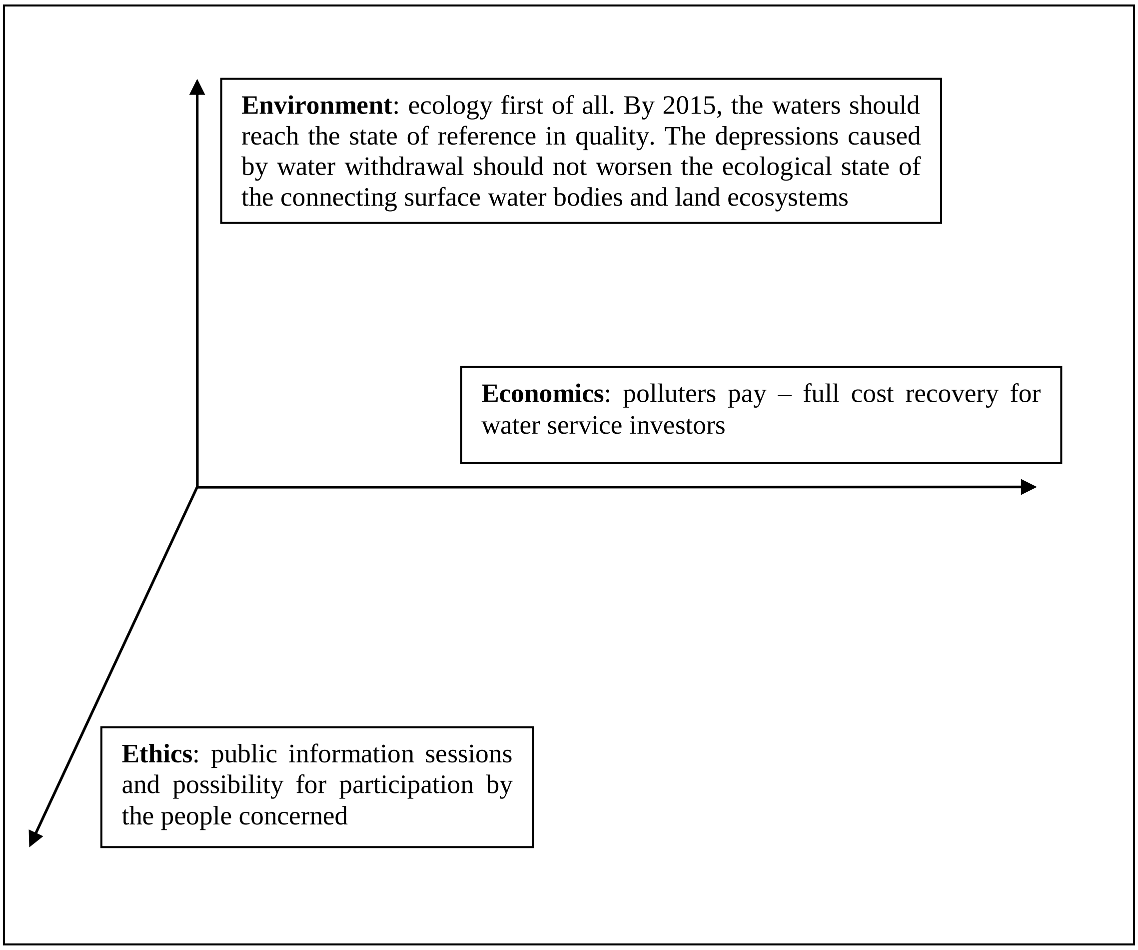


Fig. 1.2.2 The Water Framework Directive applied for karst water, explained in 3 E's [Lénárt, 2004; based on Holló, 2003 and Barraque, 2003]

As we can see, the evaluation of groundwater is present among the most important issues. The Water Framework Directive gives an opportunity to consider groundwater equal to surface water in our area. The forming of our water management strategy and law should be done according to this.

To look at the subject from three equally important points of view and to work them out by covering all the details is too extensive to be fit into this dissertation. Therefore I will primarily deal with the ***environment issue***, taking into consideration the economic approach, not forgetting the ethics approach either.

1.3. The problems of transboundary aquifers

Besides the professional-hydrogeological evaluations of transboundary aquifers ***[Biondic and Bakalowicz, 1995; Almássy and Buzás, 1999; Puri and Arnold, 2002]*** nowadays the economic-social issues are getting more and more important and these problems are being examined very thoroughly ***[Barraque**, **2003a; Garrido 2003; Hochstetler 2003; Serra, 2003]***, ***(Figure 1.3.1)***.

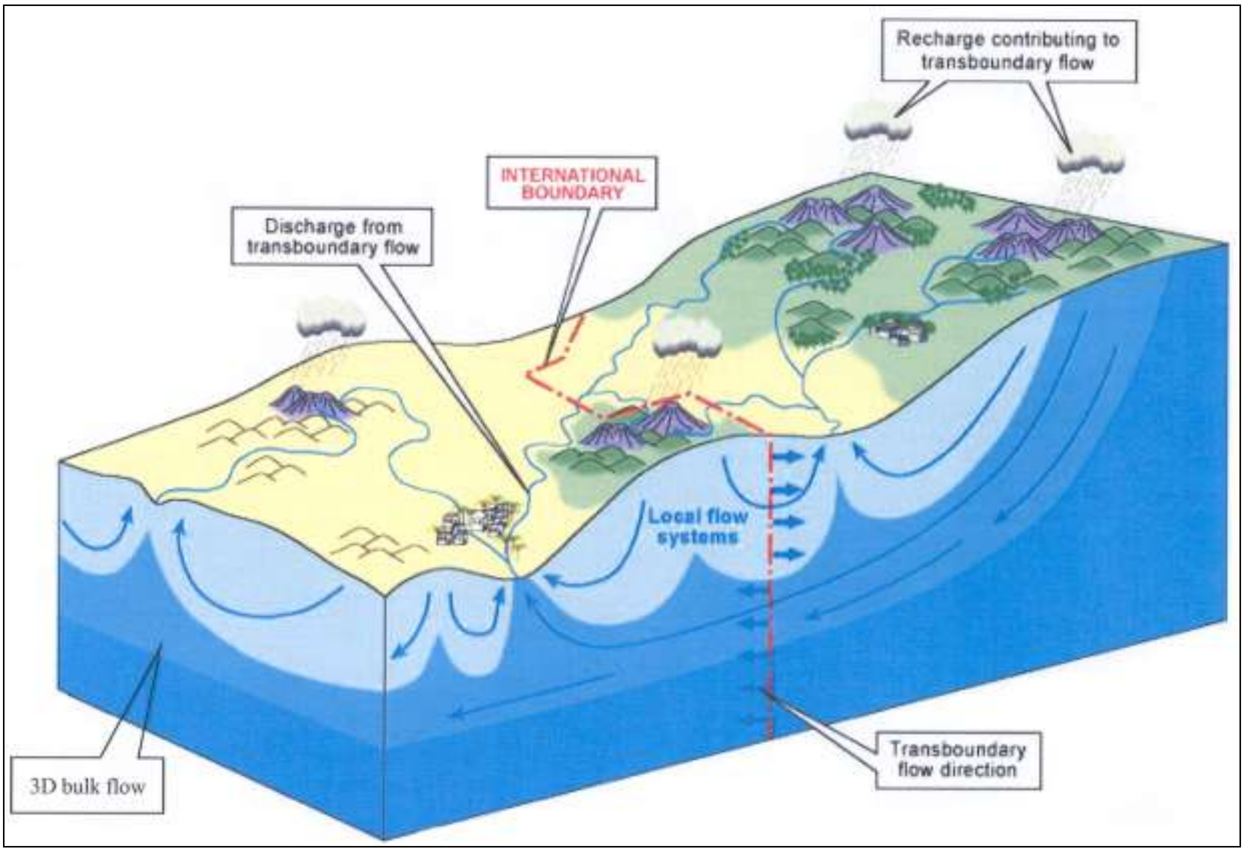


Fig. 1.3.1 Schema of transboundary aquifers [Puri and Arnold, 2002]

Lately there is increased interest in the evaluation of the transboundary water resources. The water as an outstanding strategic element is being dealt with by the NATO Science for Peace Program ***[Dassargues et al., 2001, 2003; Lénárt et al., 2003, 2004a; Szabó et. al., 2003]***.

One of the most important issues in the evaluation of the transboundary surface and subsurface water bodies is the stance of Hungary and Slovakia, since they are sharing 669 km of their state borders ***[Skultéty and Dőmény, 2000; Őri and Dőmény, 2002; Puri and Arnold, 2002], (Figure 1.3.2)***. This case is getting even more complex when we realize that this is the only area that contains karstic rocks on both the surface and underground. The individually separated evaluation of the Aggtelek Karst and the Slovak Karst (their common name before Gomor-Turna Karst) has been going on for a long time, but the professional relationship between the two countries is still not effective enough ***[Klaučo and Filová, 1996; Móga, 1998; Havas et al., 2003]***.

The evaluation of the transboundary water resources is different on each side of the border, in rate, in standard and in point of view. (The parties are just learning the opportunities and the importance of joint work.) In order to help in this problem, the evaluation of Bükk Mountains gets the emphasis in this paper. The boundaries of Bükk Mountains are well-drawn, no major mining activity is disturbing the area, professionally thoroughly examined, its environment and water resources protected by law. The area includes a national park and the water company's protective zones. (The caves of the Aggtelek Karst and the Slovak Karst are part of the World Heritage. There are biosphere reserves and ramsar sites on both areas. Delineation of further water protective zones is in process ***[Bartus et al., 1982; Bolner-Takács and Székely, 1995; Rozložnik and Karasová, 1994; Hevesi and Kocsis, 2003; Gunn, 2004]***. The main reason for my choice is, of course, that the Bükk Mountains in many ways are very similar to the karstic mountains at the Hungarian-Slovakian state border, and that the two areas are well comparable.

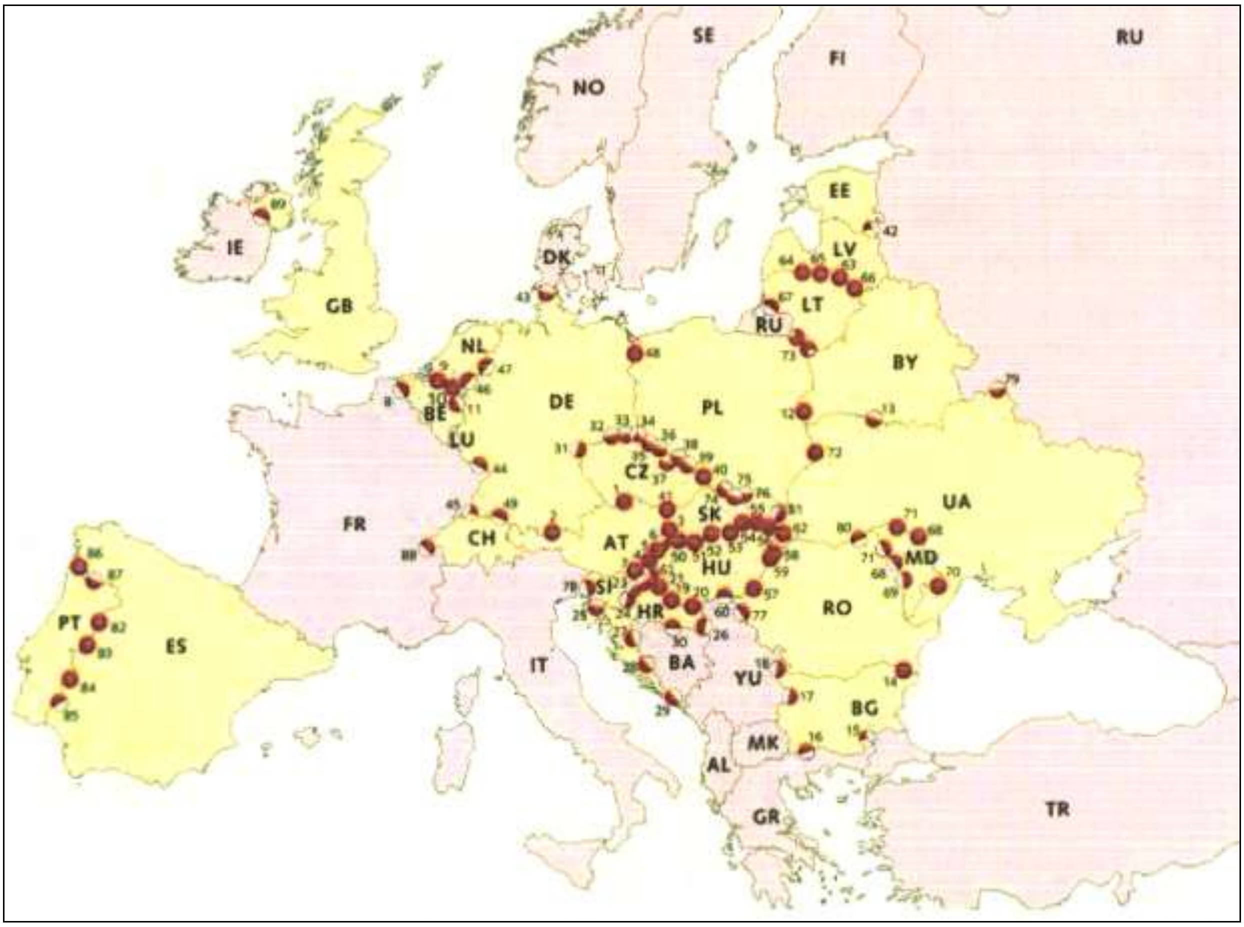


Fig. 1.3.2 Transboundary waters in Europe [Puri and Arnold, 2002]

The Hungarian-Slovakian Joint Commission on Transboundary Waters appointed the most part of the Aggtelek Karst and the Slovak Karst as the pilot area of the transboundary groundwater resources.

The Aggtelek Karst – Slovenský Kras is a hydrogeological unit divided by the state border between the Republic of Hungary and the Slovak Republic. It has been identified by both countries as a common aquifer in the Inventory of Transboundary Groundwaters ***(Figure 1.3.2)***.

The Aggtelek Karst – Slovenský Kras (together the Gömör-Torna/Gemer-Turna Karst) provides groundwater resources of good quality in both countries. The caves of the area are part of the World Heritage Program. While the cooperation on expert level between the two countries' scientific institutions has a long history, a well–based water resource management in both countries requires liable data from the aquifer as one unit. This goal is to be served by the implementation of the "Guidelines on Monitoring and Assessment of Transboundary Groundwaters".

Figure 1.3.3 [Havas et al., 2003] shows the pilot area and the test area, portraying the hydrological units of Slovak Karst as well.

- Ardovo hydrogeological unit (text: Plešivec – Silická Brezová), connecting to Haragistya-Szelcepusztai Karst on the Hungarian side
- Kečovo hydrogeological unit, connecting to the Aggtelek Plateau on the Hungarian side
- Bukový Vrch hydrogeological unit Dolný Vrch hydrogeological unit , connecting to the plateaux of Alsó-hegy on the Hungarian side

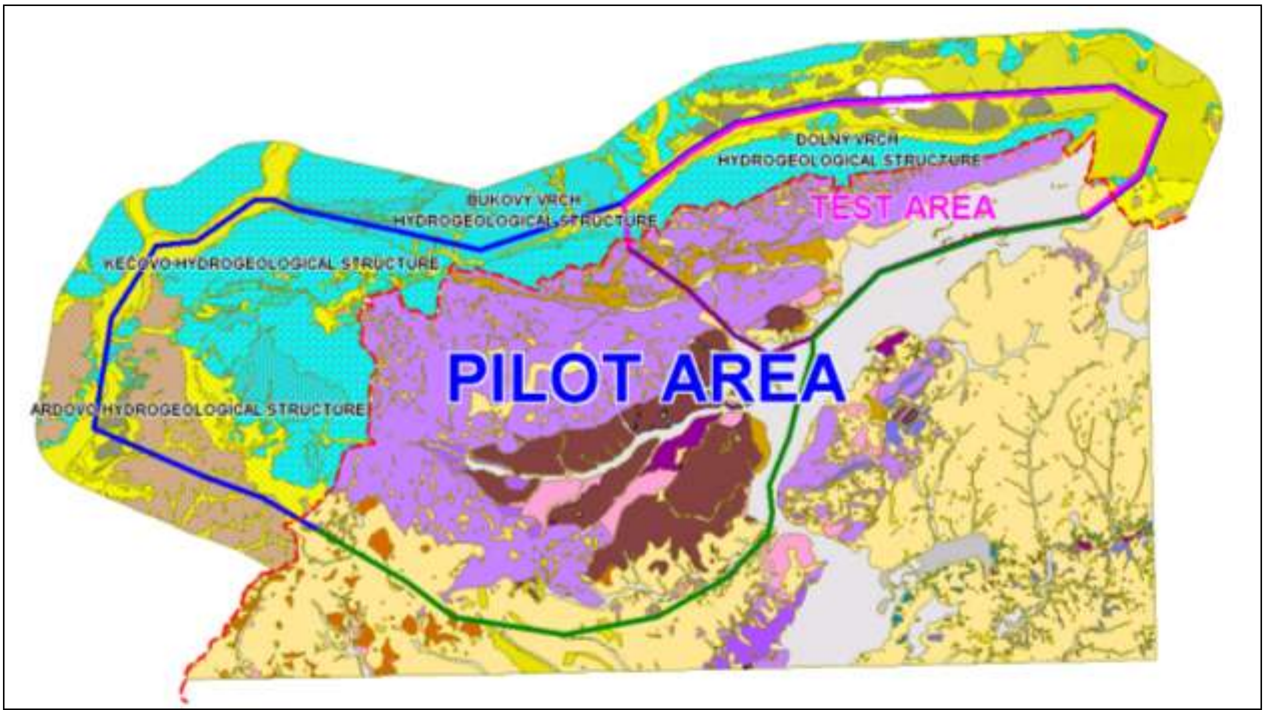


Fig. 1.3.3 Geological Services Map Connection [Havas et al., 2003]

On ***Figure 1.3.4*** one can see the draft geological map of the area, which is probably based on the work of ***Lexa et al., 2000***. It is clear that the karst system consists of parallel anticlines and synclines of East to West direction with variable widths. (This very same direction can be seen in the Bükk Mountains as well.) According to the boundaries of different structures by major tectonic faults, delineated are several tectonic units, which can be considered as independent hydrogeological unit s. (Above I have listed the hydrogeological unit s of the pilot area.)

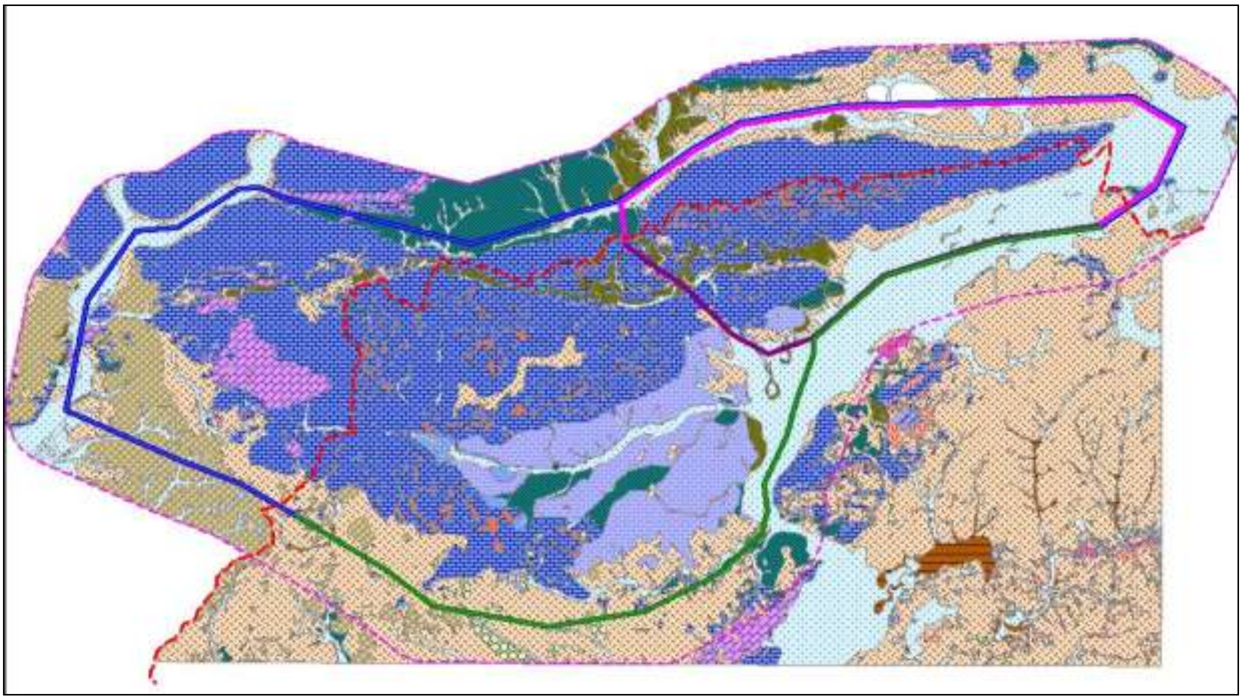


Fig. 1.3.4 Final Geological Map Draft version [Havas et al., 2003]

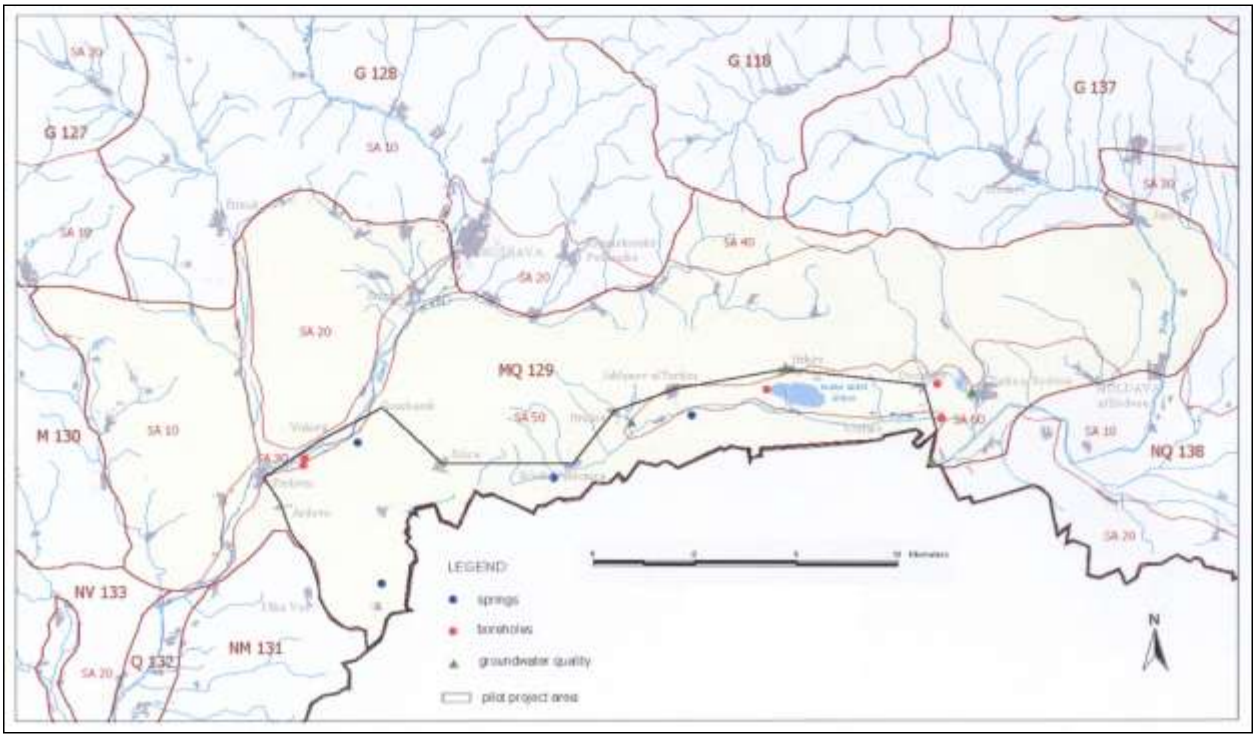


Fig. 1.3.5 Monitoring plan – Slovak Republic (Slovak Karst – the hydrogeological unit MQ 129) [Havas et al., 2003] (Legend only applies to our study area, based on Šalagová et al., 1997 and Tometz, 2000: SA 10 – partial groundwater zone among Muraň, SA 20 – partial groundwater zone of the Plešivec plateau; SA 30 – partial groundwater zone of the Štítnik and Slaná valleys; SA 40 – partial groundwater zone of the Kováčová; SA 50 – partial groundwater zone of Silická, Horný vrch, Zadielská, Jasovská and Dolný vrch plateaus; SA 60 – partial groundwater zone Neogene and Quarternary of the Turňa Basin)

The hydrology of the Gömör-Torna/Gemer-Turna Karst is characterized by the absence of surface runoff and the almost total infiltration of precipitation through numerous fissures and faulted zones into the karstic carbonate rocks. The water percolates rapidly and is accumulated inside the carbonate massif.

Figure 1.3.5 shows the monitoring system on the Slovak side, ***Figure 1.3.6*** shows the monitoring system on the Hungarian side. Both of them are based on the work of ***Havas et al., 2003***.

There are 4 springs and 5 monitoring wells in the valley on the Slovak side of the planned common monitoring system. On the Hungarian side 14 springs and 2 sinkholes can be found, in which water yield measurements would take place. In 2 karst water monitoring wells and in 2 cave creeks the water level would be measured. Meteorological data would be collected at one complex meteorological station and at 2 precipitation monitoring stations. Most of these measurements are already in process presently.

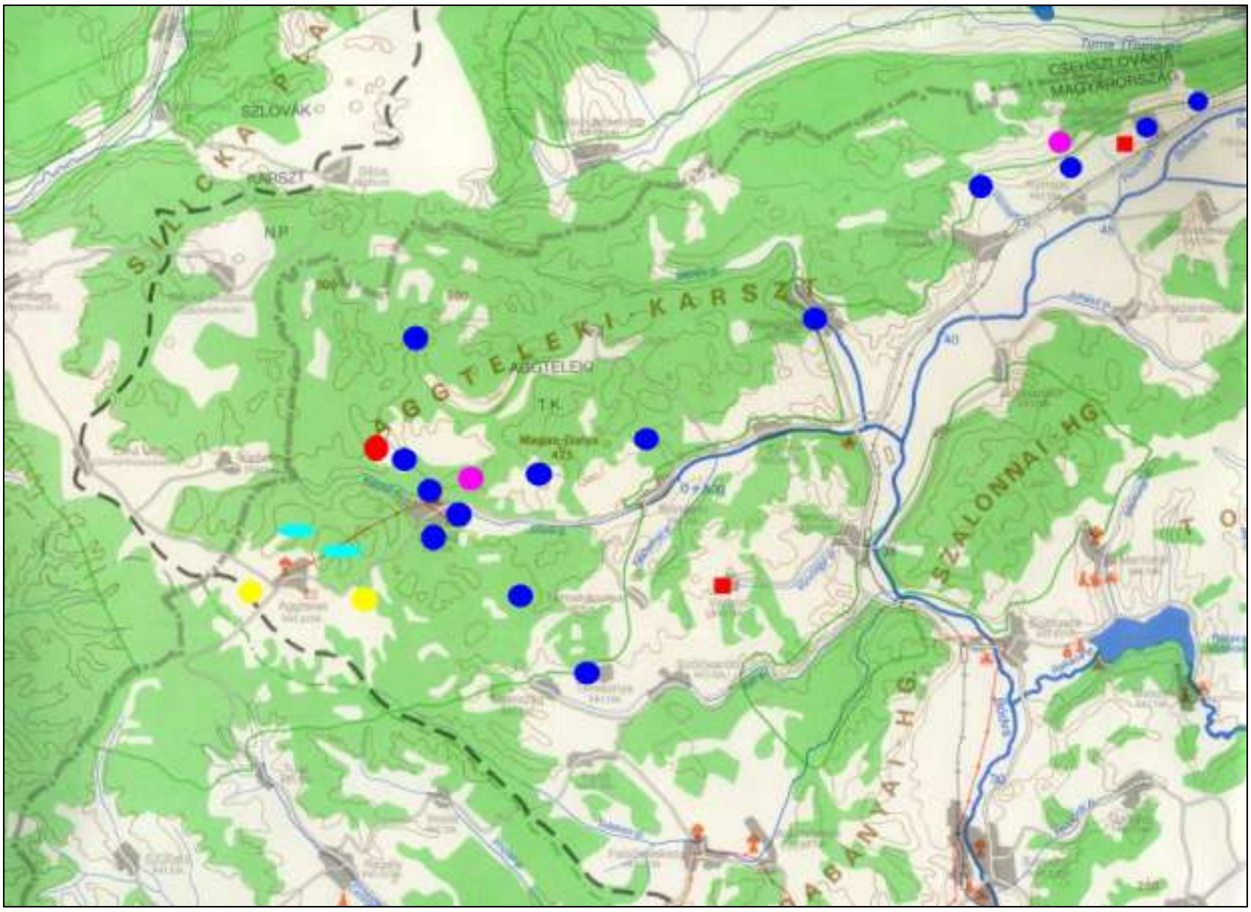


Fig. 1.3.6 Monitoring plan – Hungary [Havas et al., 2003]
(Legend: dark blue circle: quantity measurements on springs; light blue ellipse: water level measurements in cave; red circle: wells for the observation of water levels; yellow circle: sinkholes; pink circle: complex meteorological station; red square: precipitation gauges)

1.4. Sustainability of karst water management

The latest evaluation of karst water resources, in Hungary, which looks at the utilizability of karst water, required a minimum correction in the results of the former evaluations. The biggest problem is to determine the amount of water discharge that should be left for environmental purposes (ecological water demand). The determination of this water amount needs a lot of further work ***[Liebe, 2002a]***.

The sustainable karst water management can be realized today by the EU Water Framework Directive. The WFD is mainly aquifer-approached, but the karst water rarely follows the borders of a surface aquifer. The WFD also emphasizes the monitoring of transboundary water resources. (In our case this applies to the Hungarian-Slovakian transboundary cold karst water resources, and from the Hungarian side the thermal karst water resources are also marked out.)

The major part of the Bükk Mountains is a National Park. Because of this, the environment protection authorities are firmly demanding a satisfactory quantity and quality of ecological water resources for their purposes. (The situation is very similar in case of the Aggtelek Karst and Slovak Karst.)

In the Bükk Mountains, ecological and society's water demands very often cannot be met, or can be satisfied only by great difficulties (in months or years with low precipitation). The satisfaction of economical water demands many times leads to confrontations with the water producers, who retrieve their resources from the Bükk.

Recognizing this problem, and to help solving it, after years of preparatory work the Miskolc Municipality brought to life the „Bükk Area Sustainable Water Management Foundation (Bükki Víz)" in May, 1998. The Foundation intends to offer long term, complex professional assistance to reconcile the conflicting interests. This area has a population of 400 000, in 90 municipalities. The Foundation wishes to help the water management problems of the region, offering professional expertise to the authorities and water producers ***[Lénárt, 1994, 1995b,c, 1999, 2000, 2004d; Lénárt and Pápai, 2000]***.

The Bükk Area Sustainable Water Management Foundation works accordingly to the environment protection and water management laws. The goals of this continuous work are:

- Supporting the protection of karst water – quantity and quality – in the Bükk area
- Supporting any activities whose purpose is to preserve the present karst water levels
- Supporting the activities whose purpose is to protect the present quality of karst water
- Supporting the preservation of current water-related sceneries
- Supporting the ideas to restore any karst water related environmental values
- Supporting the reasonable and necessary karst water utilization and usage
- Helping to balance for the long term the ecological and economical water demands, in accordance with the water policy of Hungary

It must be stated that at the time of establishing the Foundation it was not a main aspect to meet the requirements of the Water Framework Directive, but the goals listed above do satisfy the purpose of WFD.

Figures 1.4.1-1.4.2 are presented in order to show the connection between the social goals, the utilization of natural resources and sustainability. I regard karst water as one of the most important natural resource of the human species ***[Chung and Fabbri, 2000; Šolar and Schields, 2000]***.

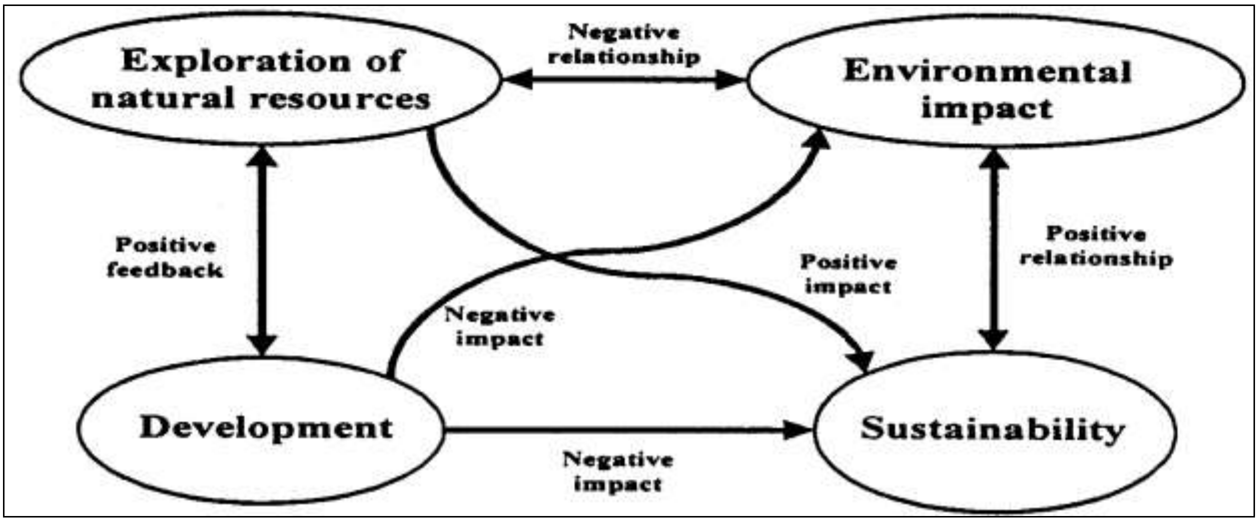


Fig. 1.4.1 Relationship between four activities: exploration, development, environmental impact and sustainability [Chung and Fabbri, 2000]

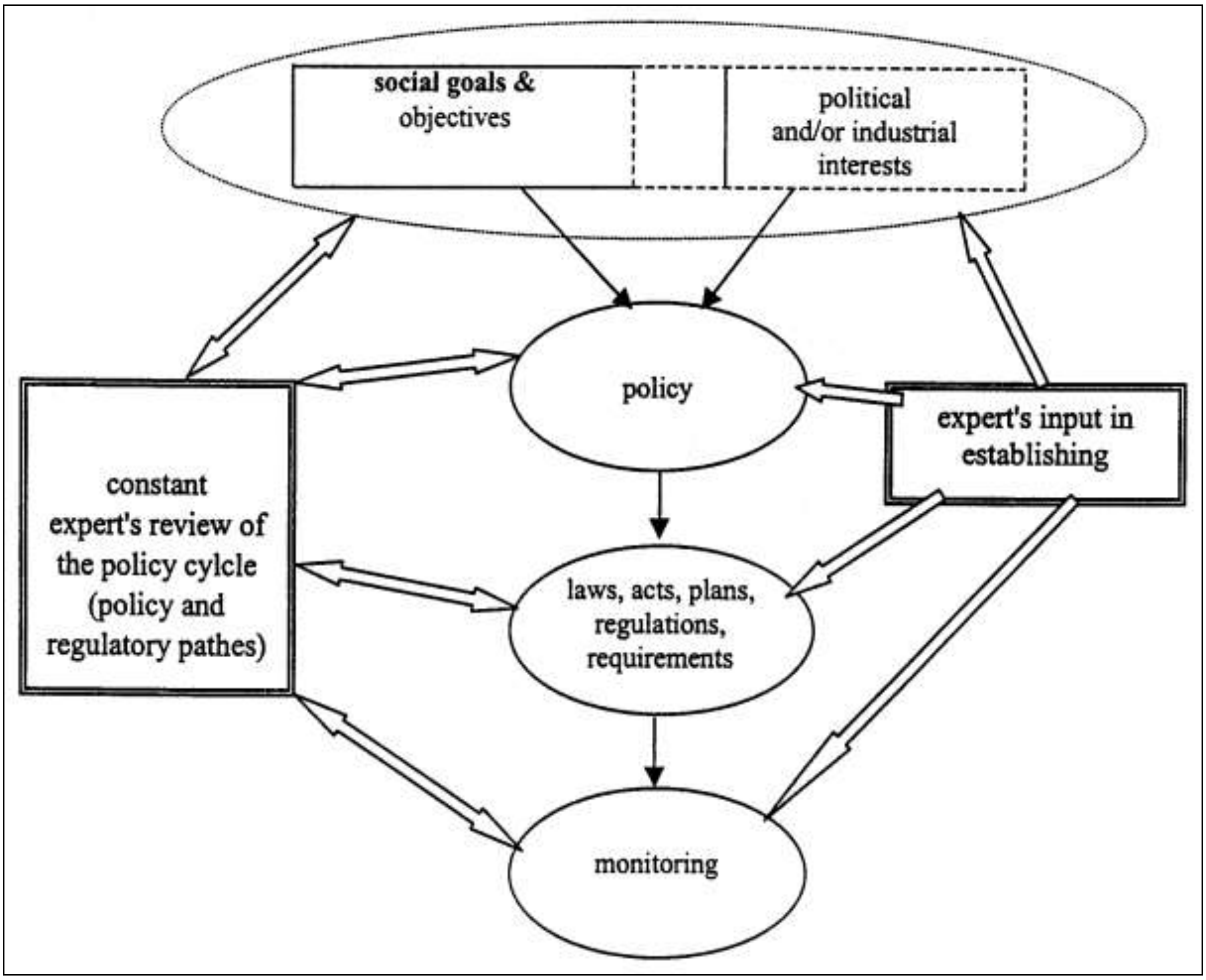


Fig. 1.4.2 Expert's role in the policy process [Šolar and Schields, 2000]

2. The database of complete evaluation

In more than three decades of my professional research I mostly have been working with data collected by myself. (My first work – my thesis – and my first publication appeared approximately 30 years ago, in May 1974.) Of course, a major amount of data and maps are originating from someone else, and then I merge the datagroups. I will mostly emphasize my own results or show the connection with the result of others in the shortened version of this dissertation.

2.5. Data originating from others

2.5.1. The site of evaluation

Figure 2.1.1 was adopted from the work of the Hungarian-Slovak Joint Commission Cooperation for Environmental and Natur Conservation Management ***[Skultéty and Dőmény, 2000; Őri and Dőmény, 2002]***.

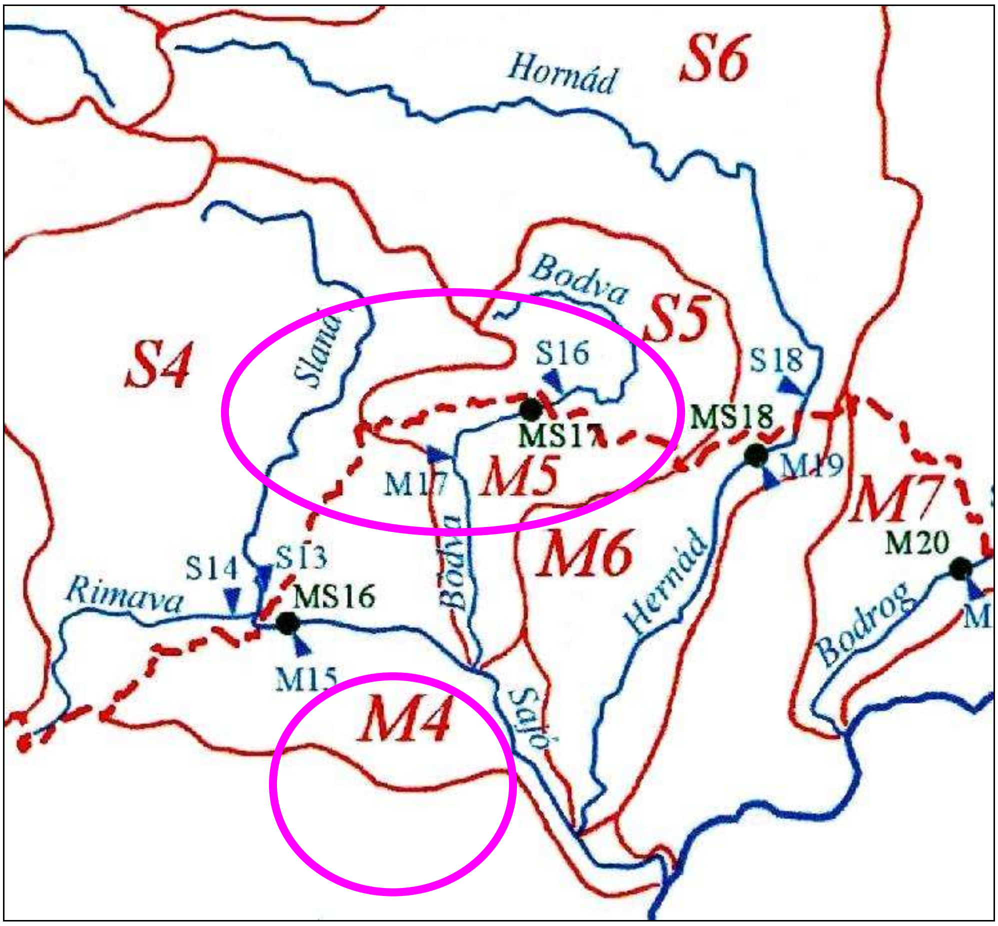


Fig. 2.1.1 Study area [Őri and Dőmény, 2002] (Legend only applies to our study area: S4: Slaná catchment area belonging to state border section; S5: Bodva catchment area belonging to state border section; M4: Sajó catchment area; M5: Bódva catchment area; S13: Water monitor, Lenartovce; S14: Water monitor, Vlkyna; S16: Water monitor, Turna; M15: Water monitor, Sajópüspöki; M17: Water monitor, Szendrő; MS16: Water quality sample, Hungarian-Slovakian common examinations, Sajópüspöki; MS17: Water quality sample, Hungarian-Slovakian common examinations, Hídvégardó)

Figure 2.1.2 shows the area of a study that was adopted from ***Hevesi and Kocsis [2003]***, and introduces the Slovakian-Hungarian border zone and the surrounding area.

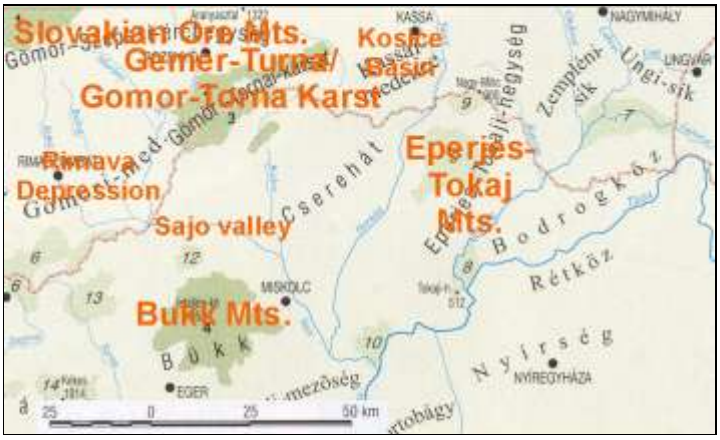


Fig. 2.1.2 The nature conservation area of the study area [Hevesi and Kocsis, 2003; English text by Lénárt] (Legend only applies to our study area: 2: Slovak Karst National Park; 3: Aggtelek NP (together: Gemer-Turna/Gömör-Tornai Karst); 4: Bükk NP)

2.5.2. Surface of the substratum

The morphology overview can be seen on ***Figures 2.1.3a,b***. In the Slovak Karst, most parts of the reserves are series of plateaux whose maximum altitude ranges between 400 and 900 m. The summits of the Plešivec Plateau reach 851 m, and those of the Silica Plateau reach 679 m. The highest elevation is reached by Pipítka (1.225 m) and the lowest point of 150 m above sea level is in the Valley of the Bódva Brook.

The highest point of the Aggteleki Karszt is the Fertés-tető at 604 m above sea level, and the average height of the karst plateaux is between 500 and 600 m above sea level. The lowest point is in the Valley of Bódva – 150 m above sea level.

The Bükk is the most Southernmore and the most extensive member of the Northwestern Carpathians. It also has the highest elevations on average. The highest point of the Bükk is Istállós-kő (959 m), and 50 of its summits is elevated above 900 m. Its lowest point is Miskolc-tapolca, where the most of the karst springs of the Bükk can be found. Miskolctapolca is about 130 m above sea level.

Fig. 2.1.3a Air photo of the study area

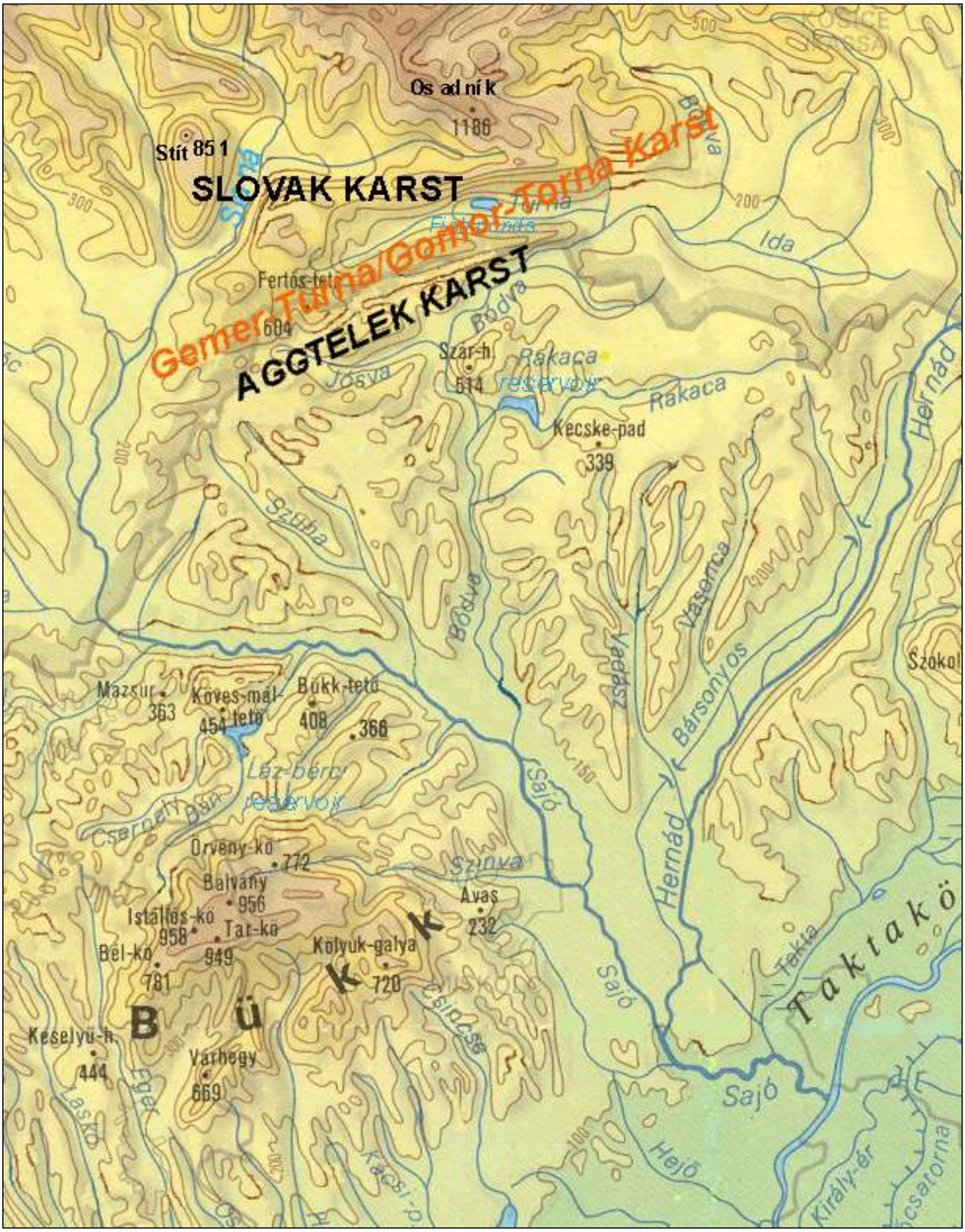


Fig. 2.1.3b Relief and hydrography of the study area [Cartographia, 1989; in: Pécsi, 1989]

The relief structure of the study area and the situation of the buried substratum are shown on ***Figure 2.1.4***, based on the work of ***Havas et al. [1995]***. From the works related to the evolvement of the surface, the works of ***Hevesi [1986], Móga [1998] and Tometz [2000c]*** is used.

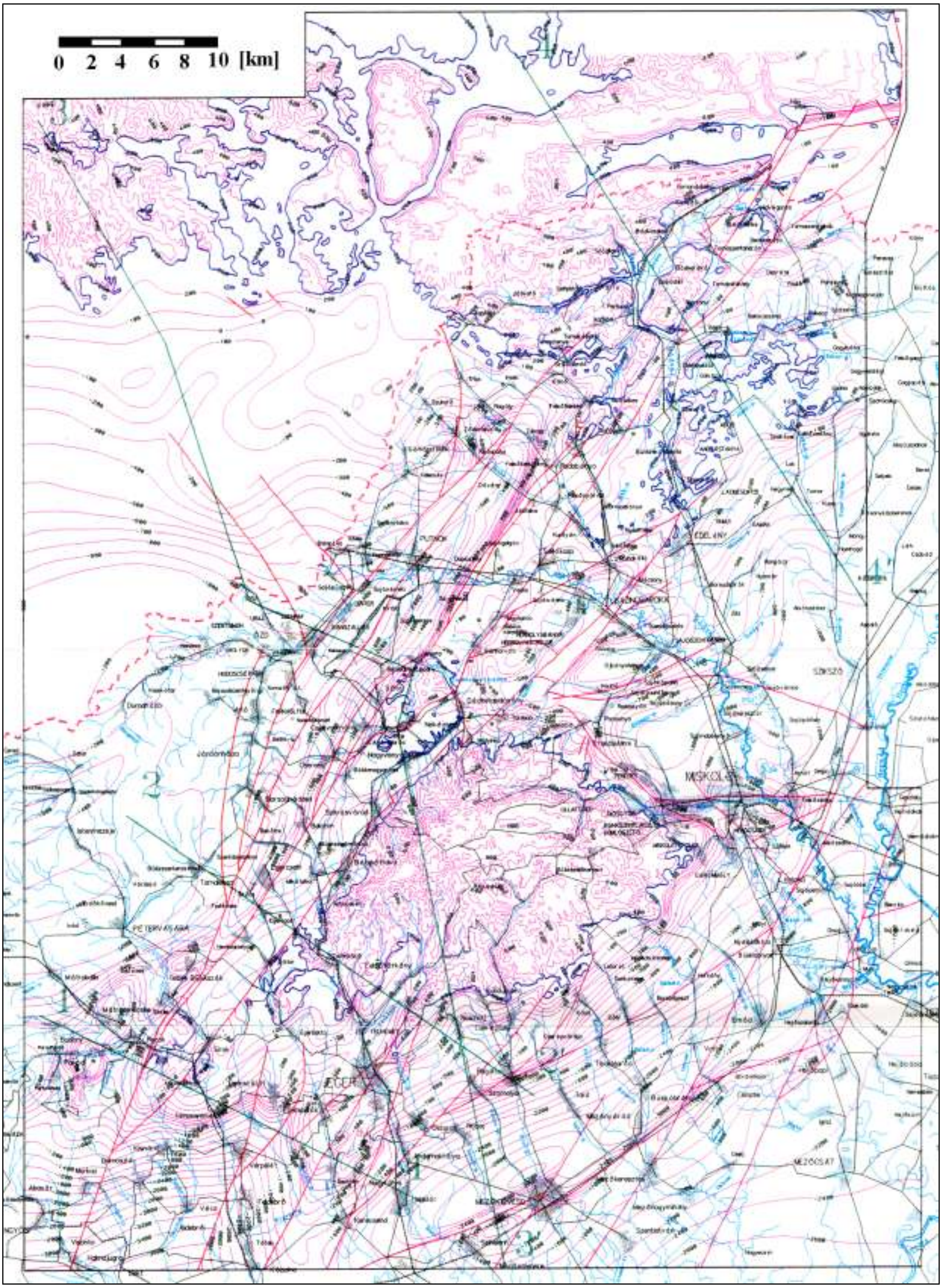


Fig. 2.1.4 The surface of the substratum in the study area [Havas et al., 1995]
(Legend: black line: way, railway; bold red line: faults; bold red discursive line: political border; bold dark blue line: border of hydrogeological unit; light blue line: river, creek; bold green line: lithological cross-sections; purple line: surface of the base mountain)

2.5.3. Hydrographic structure

For an overview of the hydrographic structure of the study area, let's see ***Figure 2.1.5*** from ***Hevesi's*** DSc thesis ***[2002]***. This simple map clearly shows that areas are hydrographically very different from each other in our study area. In case of Bükk, every spring of creeks exits at either at the edge or in the interior of the mountain. Contrary to this, on the Southern part of the Gemer-Turna / Gömör-Torna Karst, we can find waters that cut across mountain parts, besides the creeks which springs exit at the mountain edge. Finally, the Northern part of the Gemer-Turna / Gömör-Torna Karst (Slovak Karst) is divided into independent morphological and hydrological units by the rivers flowing from North.

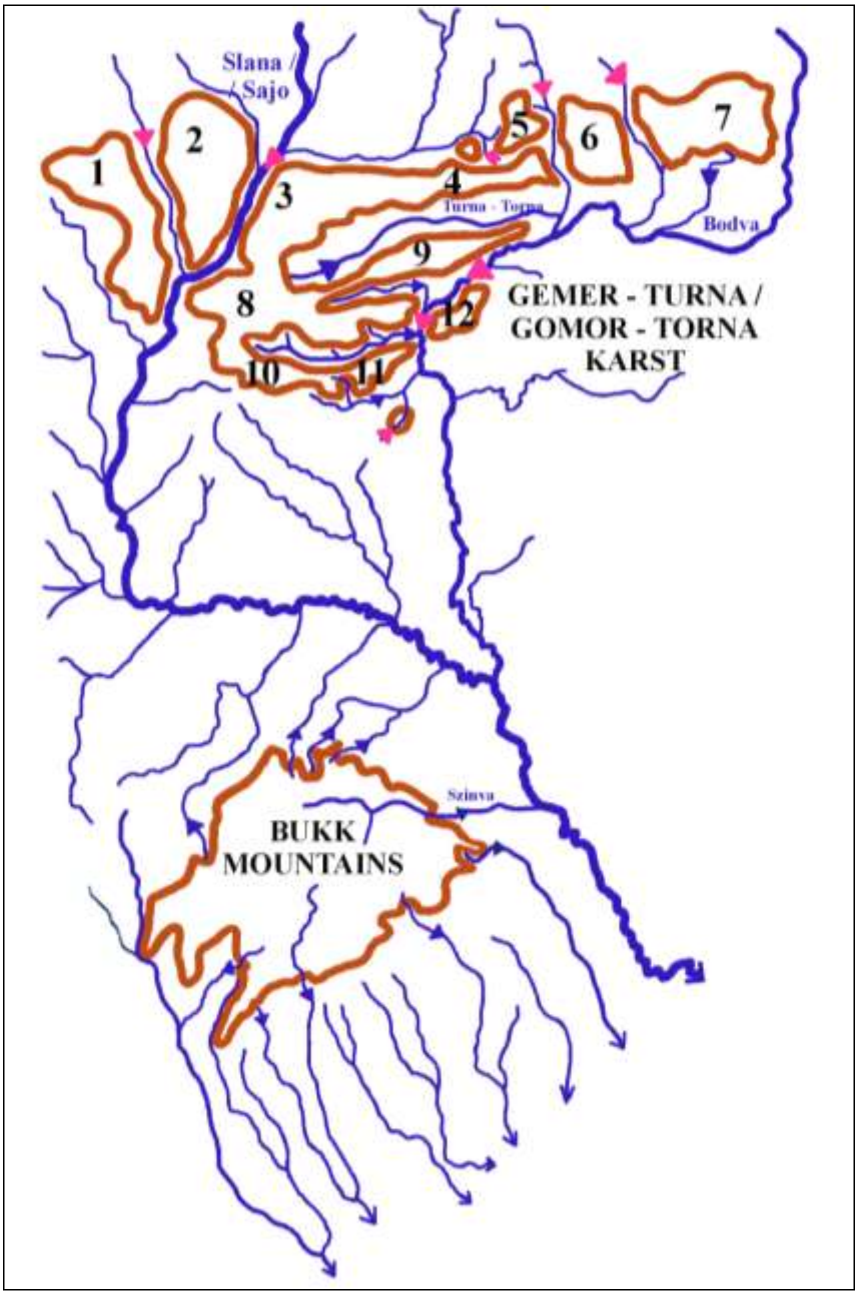


Fig. 2.1.5 Hydrographic map of the study area [Lénárt, 2005; based on Hevesi, 2002] (Legend: 1: Koniar (Konyárt); 2: Plešivec (Pelsőci) Plateau; 3: Silica (Szilicei) Plateau; 4: Horný vrch (Felső-hegy) Mountain; 5: Borka (Barkai) Plateau; 6: Zádiel (Szádelői) Plateau; 7: Jasov (Jászói) Plateau; 8: Aggtelek Karst; 9; Dolný vrch (Alsó-hegy) Mountain; 10: Galyaság; 11: Rudabánya Mountains; 12: Szalonna Mountains; Red triangle: watercourses cutting through mountain; blue triangle: watercourses exiting from mountain)

2.5.4. Geological structure overview

General geological-tectonical map of the study area is shown on ***Figure 2.1.6 [Brezsnyánszky, in: Pécsi, 1989]***. ***Figure 2.1.7*** shows its simplified version that presents the geological-tectonical characteristics of the entire Carpathians ***[Brezsnyánszky et al., 2000]***.

The geological structure of the study area is introduced on ***Figure 2.1.8***, based on the work of ***Lexa et al. [2000]***. This work deals with the entire Northwestern Carpathians and only touches on my study area. I use this map because of its simplicity and because it uses the same approach as mine. (This map and its comments were created by using a vast amount of Slovak and Hungarian documentation. Unfortunately there is no room to list them all.)

The geological map of the Gemer-Bükk area 1:100.000 ***[Less and Mello (editors), 2004]***. ***Figures 2.1.9-2.1.11*** shows more detailed information regarding the study area.

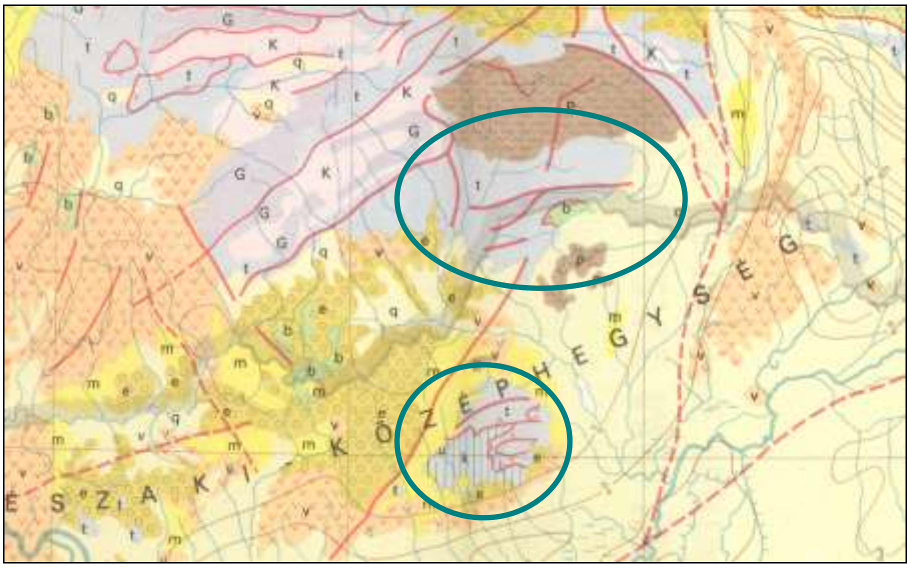


Fig. 2.1.6 General geological-tectonical map of study area [Brezsnyánszky, in: Pécsi, 1989]

Fig. 2.1.7 The major terranes, units and tectonic lines of study area [Brezsnyánszky et al., 2000]

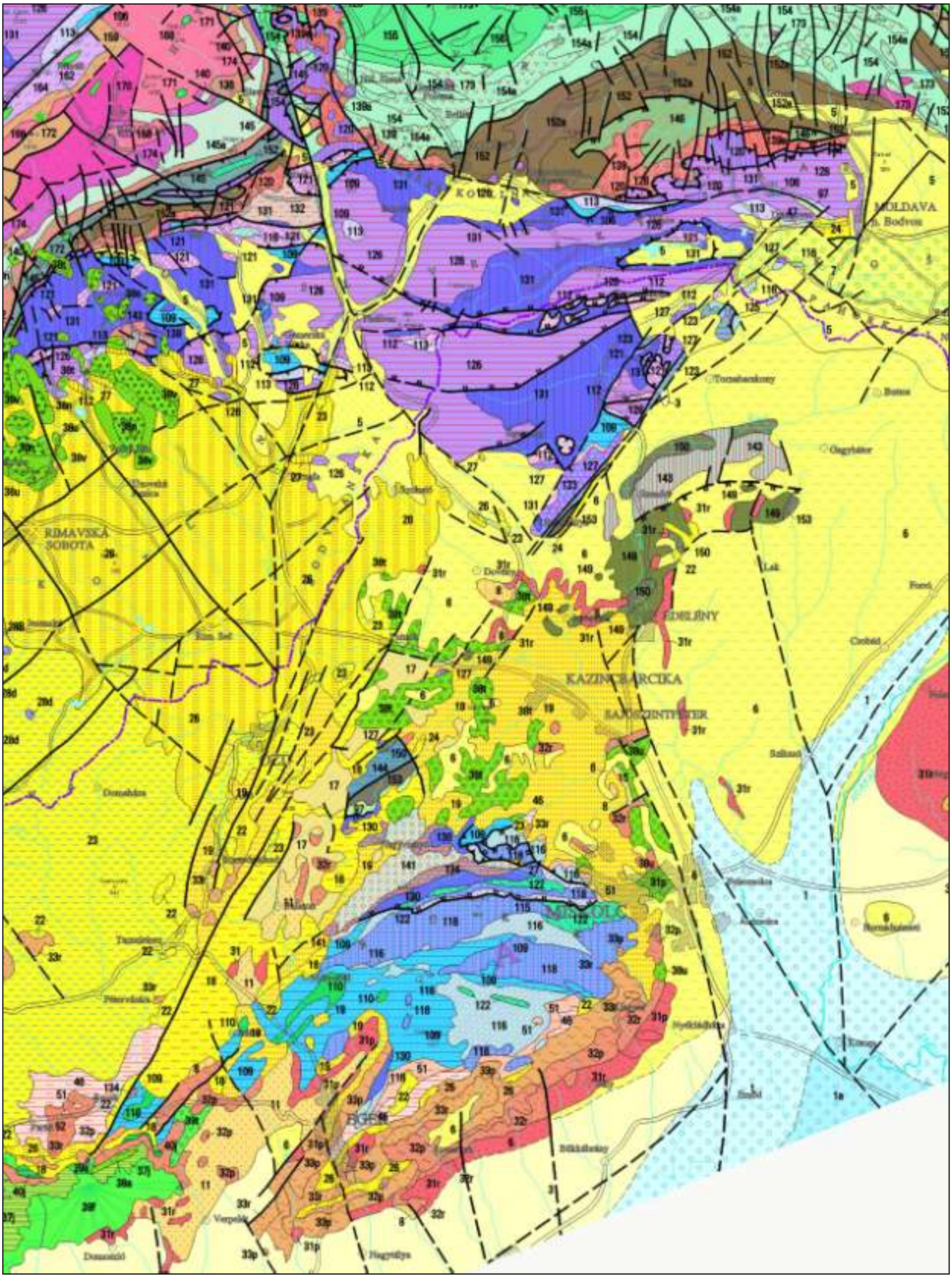


Fig. 2.1.8 The geological structure of the study area [Lexa et al., 2000]
(Legend is the next page)

Legend of Geological Map by Lexa et al., 2000 (Only applies to our study area)

NEOGENE-QUATERNARY BASINS: ***3***: grey and variegated clays, silts, sands, gravels, thin lignite seams, freshwater limestones, and tuffites horizons (Dacian-Romanian); ***5***: variegated kaolinite clays, sands, gravels, rare lignite seams (Pontian); ***6***: grey, mostly calcareous clays, silts, sands, gravels, lignite seams, freshwater limestone horizons (Pannonian-Pontian); ***11***: grey calcareous clays/claystones, siltstones, sands/sandstones, conglomerates, acid tuffs, bentonite, limestones, diatomites and evaporites (Sarmatian); ***17***: grey calcareous silts/siltstones, clays/claystones, sands/sandstones, subordinate gravels/conglomerates, Algal and Ostrea limestones, coal seams, tuffs/tuffites, locally anhydrites (Early Badenian); ***18***: grey and variegated, often calcareous claystones, sandstones, conglomerates, gravels, breccias, evaporites, subordinate diatomites and thin coal seams in the foredeep also lumachella limestones (Karpatian); ***19***: grey claystones, siltstones, sands, organodetritic sandstones, conglomerates, coal seams, algal limestones (Ottnangian); ***22***: variegated clays, sands, gravels, rhyodacite tuffs (late Eggenburgian, also early Ottnangian in Hungary); ***23***: calcareous siltstones, claystones, sandstones, tuffites, variegated and grey clays, coal seams, conglomerates, breccias, organodetritic limestones (Eggenburgian); ***24***: conglomerates, gravels, sands, sandstones, siltstones, clays, claystones, subordinate thin coal and limestones – continental facies (Early Miocene); grey calcareous siltstones, sands/sandstones, conglomerates, variegated clays, carbonaceous clays, thin coal seams (Egerian to Karpatian in Hungary); ***27***: organodetritic limestones, conglomerates, marlstones (Egerian)

NEOGENE-QUATERNARY VOLCANIC FORMATIONS: rhyolites and rhyodacites: ***31***: Sarmatian-Pannonian; ***32***: Karpatian-Badenian; ***33***: Early Miocene; ***39***: Badenian (Sarmatian? in the Borsod Basin); volcanic forms and facies associations: ***p***: ignimbrites, pumice tuffs, tuffs (proximal facies); ***r***: fine, primary and reworked tuffs (distal facies); ***u***: epiclastic volcanic conglomerates and sandstones

PALEOGENE OF THE INNER CARPATHIANS AND BUDA PALEOGENE: ***46***: sandstones, claystones, marls, coal seams, conglomerates, tuffites, variegated clays (Oligocene); ***51***: organogeneous and allodapic limestones, claystones, marlstones, coal seams, variegated clays (Eocene)

INNER CARPATHIAN, AUSTROALPINE AND DINARIC UNITS: MESOZOIC: ***97***: marls, carbonate sandstones, (also as flysch), limestones, conglomerates (Brezová and Gosau Groups) (Senonian); ***106***; limestones, sandstones, sandy and spotted limestones, nodular and radiolarian limestones, radiolarites ("basinal facies") (Rhaetian-Kimmeridgian); ***109***: shales, radiolarites, sandstones and olistostromes (Meliata Fm.), with rhyolites (Telekesoldal Fm.) (Lias-Callovian), shales, radiolarites, ooidal limestones and olistostromes of Bükk (Middle-Late Jurassic); ***110***: basic magmatites of Bükk (Szarvaskő Basal and Tardos Gabbro) (Middle Jurassic); ***112***: variegated limestones, locally shales (Norian-Rhaetian); ***113***: pale, mainly organodetritic limestones and dolomites (Carnian-Rhaetian); ***115***: dark-grey shales and sandstones (Carnian); ***116***: metamorphosed cherty limestones of the Turna and Bükk (Late Triassic); ***118***: metamorphosed, light-grey, massive limestones of Bükk (Ladinian-Carnian); ***120***: dolomites, recrystallized limestones with glaukophanites, phyllites and metasiltstones (Middle to Late Triassic, Jurassic); ***121***: dolomites, metamorphosed light massive and dark cherty limestones, shales, tuffites (Turna sequence) (Middle-Upper Triassic-Jurassic?); ***122***: immediate and basic volcanics of Bükk (Szentistvánhegy Metaandesite, Szinva Meteabasalt) (Ladinian-Carnian); ***123***: metamorphosed, light-grey, massive limestone of the Turna sequence (Anisian); ***125***: dark and light limestones, dolomites, and cherty limestones (Anisian-Carnian); ***126***: limestones and dolomites ("carbonate platform") (Anisian-Carnian); ***127***: limestones, allodapic limestones ("basin facies") (Middle Triassic); ***130***: oolitic limestones, variegated sandstones and marls (Scythian-Anisian); ***131***: sandstones, shales, calcareous shales, limestones, dolomites, locally rauwackes, gypsum, anhydrites: a-rhyolites (Late Permian-Scythian); **LATE PALEOZOIC**: ***132***: shales, sandstones, rhyolites volcanics, subordinate dolomitic limestones and phosphatic sandstones (Late Permian); ***134***: dark algal limestones with dolomites and thin black shales intercalations (Middle to Late Permian); ***139***: conglomerates, sandstones, rare rhyolites volcanics (Rožnava Fm.), a-strongly deformed (Early Permian); ***141***: shales, organodetritic limestones, conglomerates, sandstones (Mályinka and Szilvásvárad Fm.) (Late Carboniferous); ***143***: phyllites, metasiltstones, sandstones, rare conglomerates, acid volcanics and carbonate olistoliths (Turiec and Szendrő Fm.) (Late Carboniferous); ***145***: metamorphosed sandstones and conglomerates, phyllites, mafic volcanics, in the upper part dolomites and magnesites, a-metabasalts, metagabbrodiorites (Early to Late Carboniferous)

EARLY PALEOZOIC OF THE GEMERIKUM, BÜKKIKUM AND GRAUWACKENZONE IN THE ALPS: ***146***: metasandstones, phyllites, rare metabasalts (Late? Devonian - Early? Carboniferous); ***149***: limestones (Szendrőlád Lmst.) (Middle Devonian); ***150***: limestones, bioherm limestones, sandy limestones, marbles, phyllites, mafic tuff intercalations (Abod, Rakacaszend, Bükkhegység and Uppony Fms.) (Devonian); ***152***: metasandstones, phyllites, carbonates, cherts, rare conglomerates, basic volcanics, a-acid volcanics (Silurian-Early Devonian); ***153***: shales, graphitic and silicic shales, cherts, sandstones, marphic volcanics, limestonea and volcanic olistolites (Tapolcsány and Strázsahegy Fms.) (Silurian-Early Devonian); ***154***: metasandstones, phyllites, carbonates, conglomerates, basic metavolcanics, a-acid volcanics (Ordovian, Silurian)

GENERAL EXPLANATIONS: geological boundaries; proved, assumed faults; proved, assumed and/or covered first order overthrust lines; proved, assumed second order overthrust lines; proved, assumed

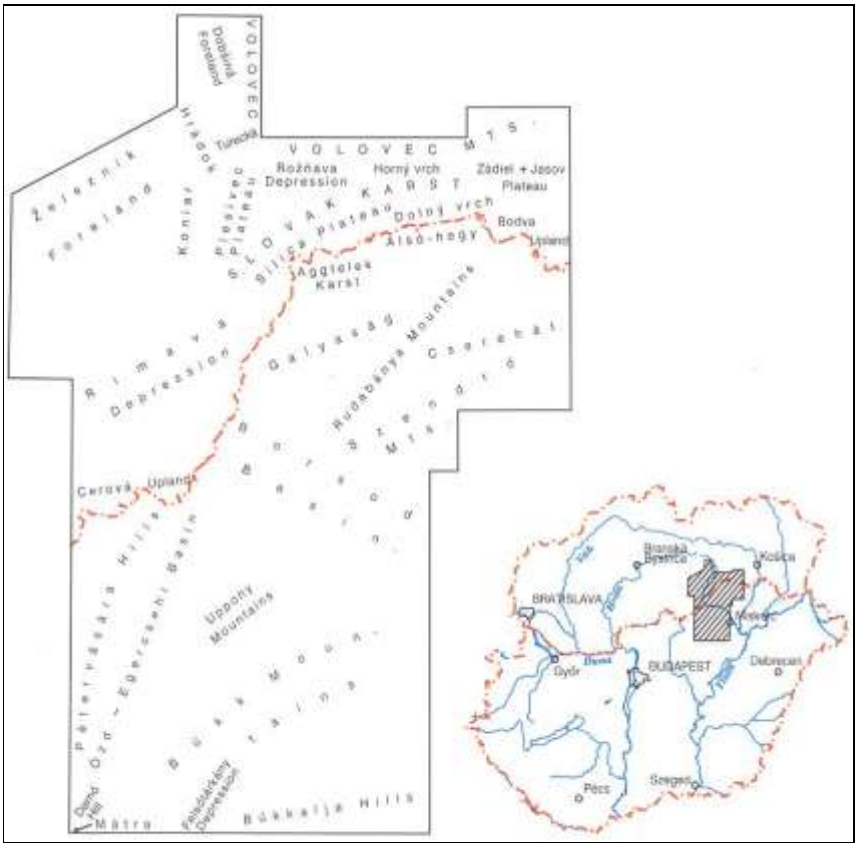


Fig. 2.1.9 The position of main geographical units of the study area [Less and Mello editors, 2004]

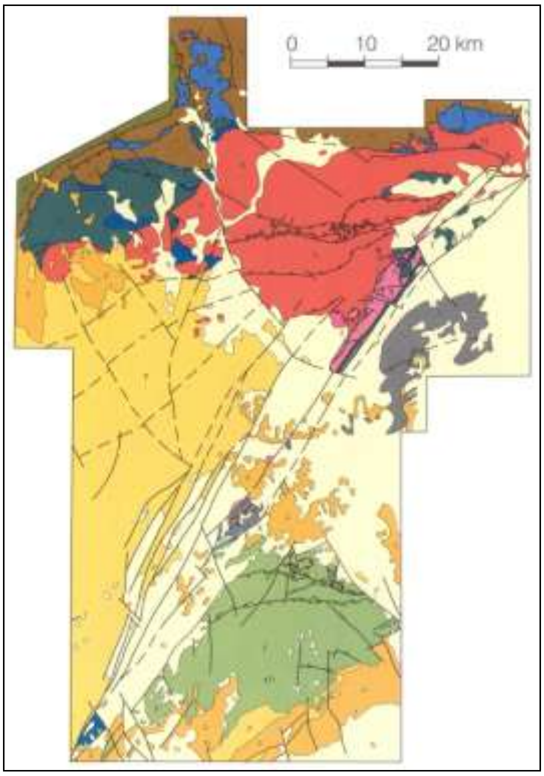


Fig. 2.1.10 The tectonic scheme of the study area [Less and Mello editors, 2004]
Fig. 2.1.11 The legend to the tectonic scheme of the study area [Less and Mello editors, 2004]

2.5.5. Hydrogeological setting

It is clearly visible that neither the geological, nor the tectonical features of the study area form a unified system. But all three areas are made up of rocks that are mostly of the same age and material ***[Balogh, 1964; Kullman, 1978, 1983, 2002, 2004; Šuba, 1979; Biely et al., 1996; Hanzel, 1996; Mello et al, 1997; Sasvári, 1999]***.

This study is basically about water management. For this reason, beside the geological-tectonical overview we have to deal with the hydrogeological setting as well. ***Figures 2.1.12-2.1.16*** displays the geological structures in map and lithological segments. (The Lexa and the MÁFI study doesn't use the very same nomenclature, but the interpretation of these differences is not the topic of this study.)

Legend to figures 2.1.12-2.1.16 [MAFI, in: Havas, 1995]

the limes of the substratum on the surface; faults in general
cherty limestone and shale; dolomite and marl
andesite (porphyrit); basalt; dolomite
evaporite; phyillite; gabbro
conglomerate; crystalline shale; marl
cherty limestone; limestone and dolomite; limestone and shale
limestone; shale; shale and limestone
basalt in shale; tertiary sediment; sandstone

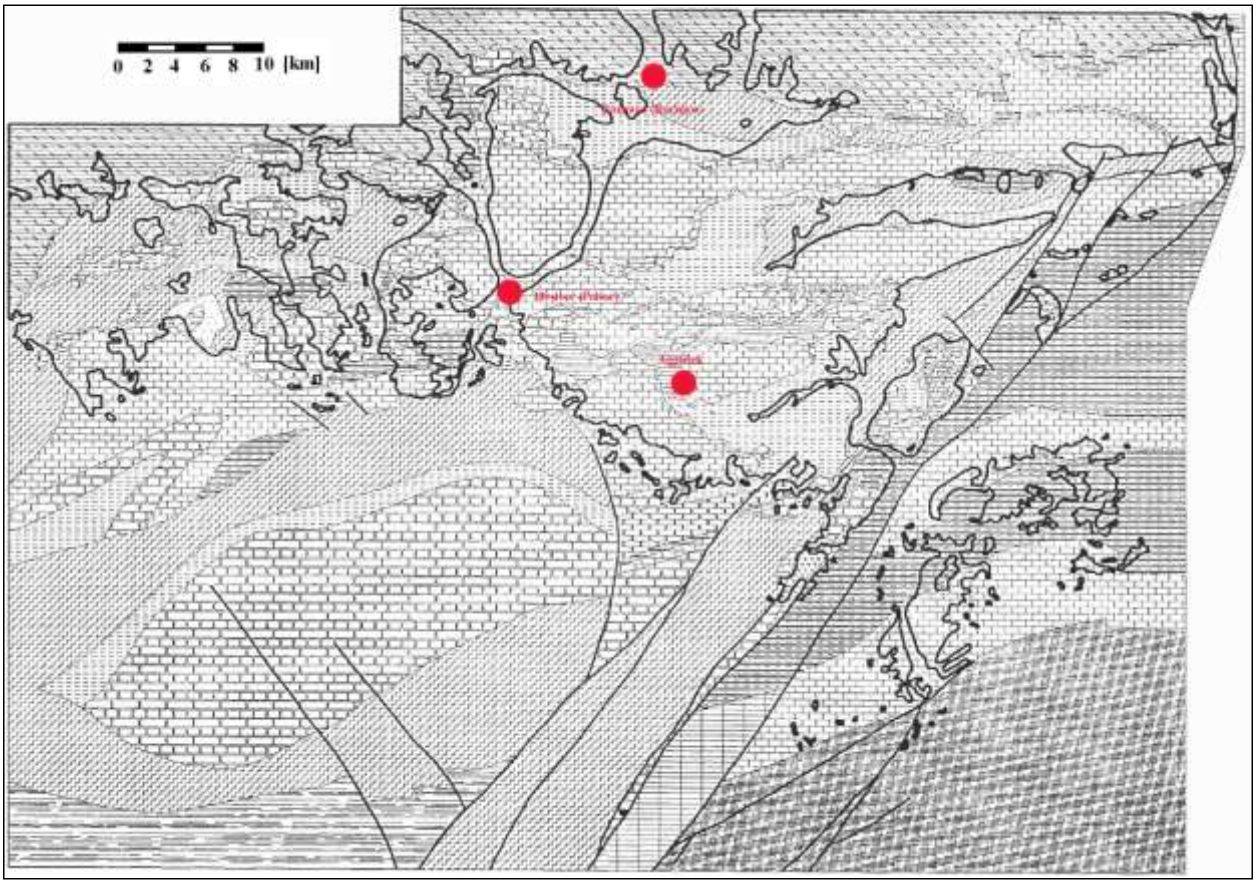


Fig. 2.1.12 The geological structure of the study area (Aggtelek karst – Slovak karst) [MAFI, in: Havas, 1995]

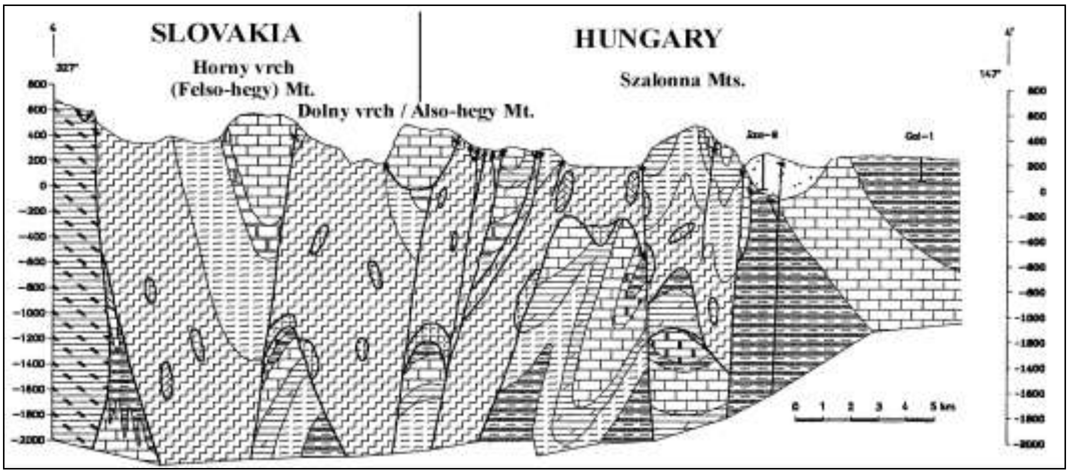


Fig. 2.1.13 Lithological cross-section of the study area (Aggtelek karst – Slovak karst) [MAFI, in: Havas, 1995] (See Fig. 2.1.4 green line, 4-4)

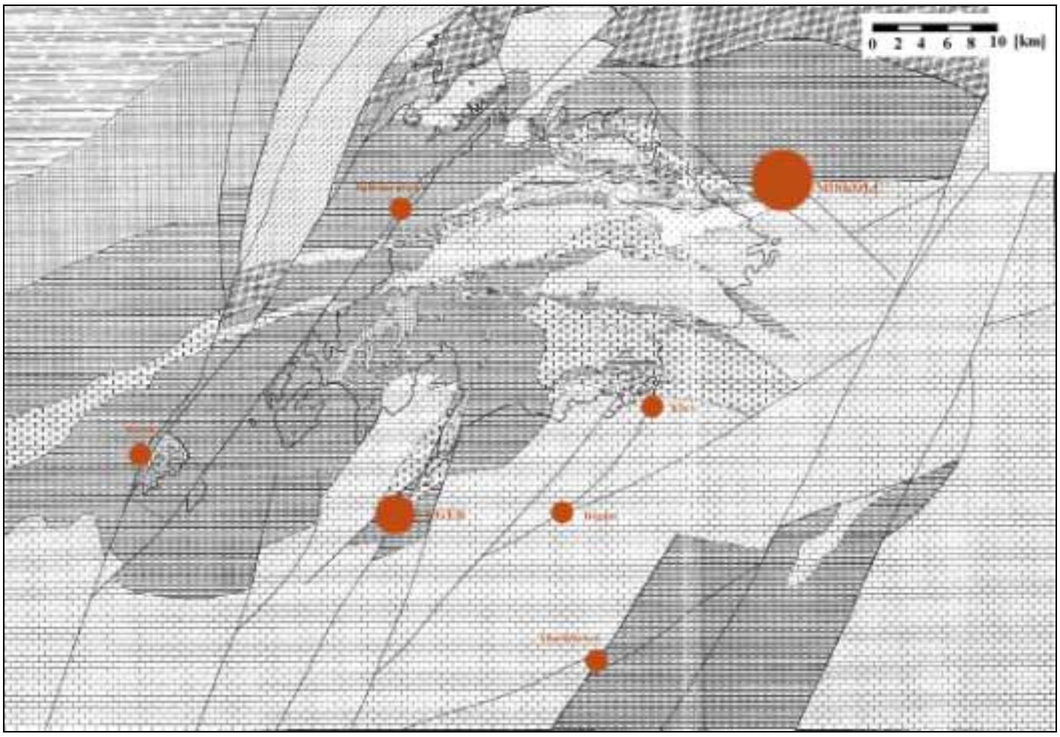


Fig. 2.1.14 The geological structure of the study area (Bükk Mountains) [MAFI, in: Havas, 1995]

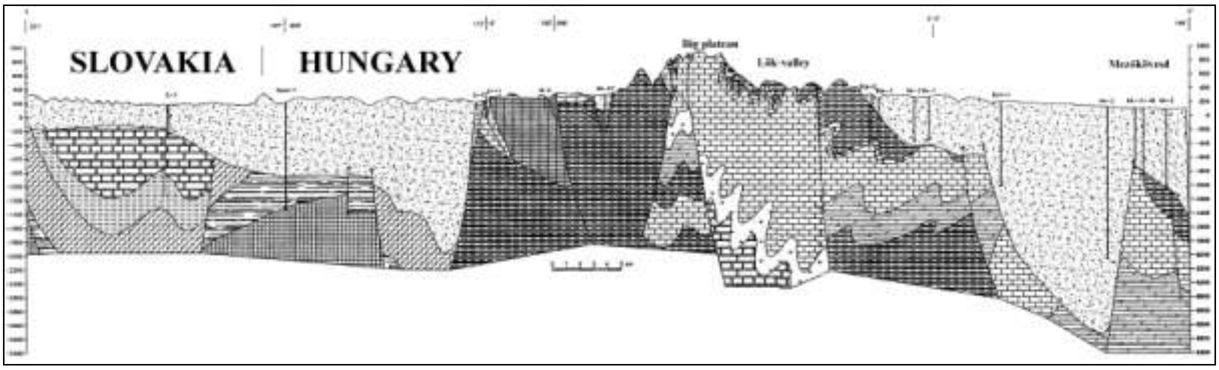


Fig. 2.1.15 Lithological cross-section of the study area (Aggtelek karst – Slovak karst – Bükk Mountains) [Less-Turtegin-Pelikán, 1994; in: Havas, 1995] (See Fig. 2.1.4, green line, 3-3

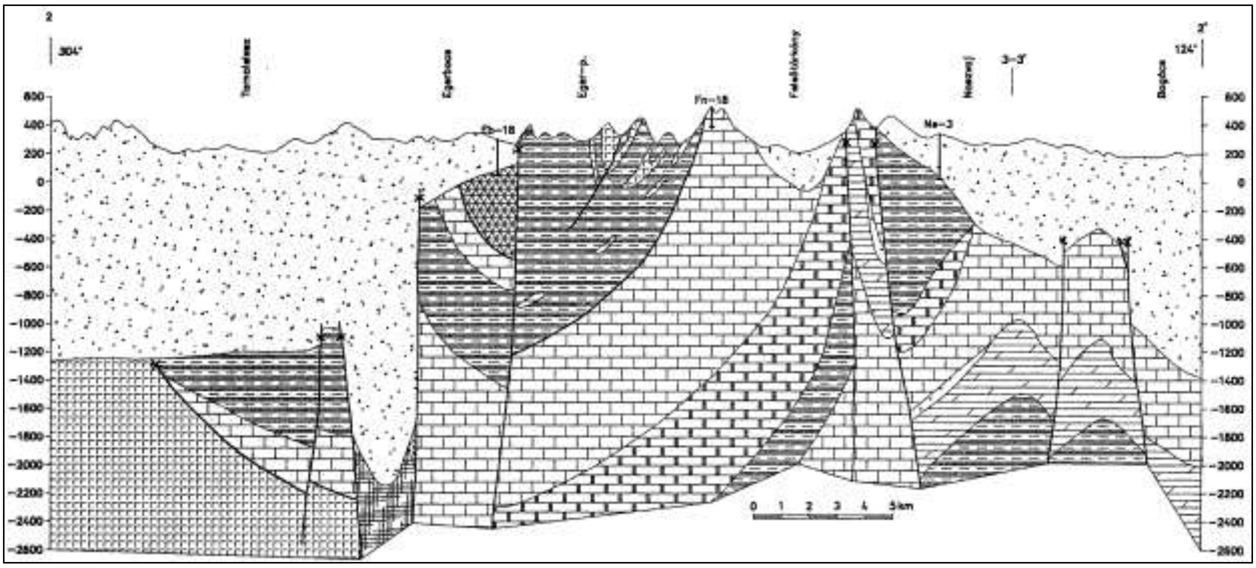
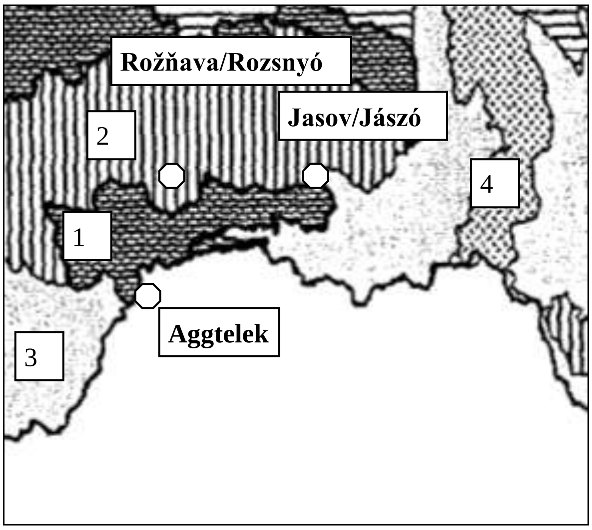


Fig. 2.1.16 Lithological cross-section of the study area (Bükk Mountains) [Gulácsy, 1994; in: Havas, 1995] (See Fig. 2.1.4, green line, 2-2)

It is not possible to give a detailed examination of the hydrogeological structure of the study area. I wish to highlight the following works that are related to the introduction of the hydrogeological structure of the Bükk Mountains, the Aggtelek Karst and the Slovak Karst: ***Szabó et al., 1966; Kullman, 1990; Orvan, 1991; Havas et al., 1995; Lénárt et al., 1997; Orvan et al., 1997; Liebe, 2002b, 2003; Havas et al., 2003***. I give an overview via the common water courses that should be marked out by the Water Framework directive. The Slovakian ***[Kullman et al., 2004]*** and Hungarian ***[Simonffy, 2003a,b]*** approach is being shown on the ***Figures 2.1.17 and 2.1.18***. The two different approaches are clearly visible. The task of the near future is to professionally reconcile these different views.



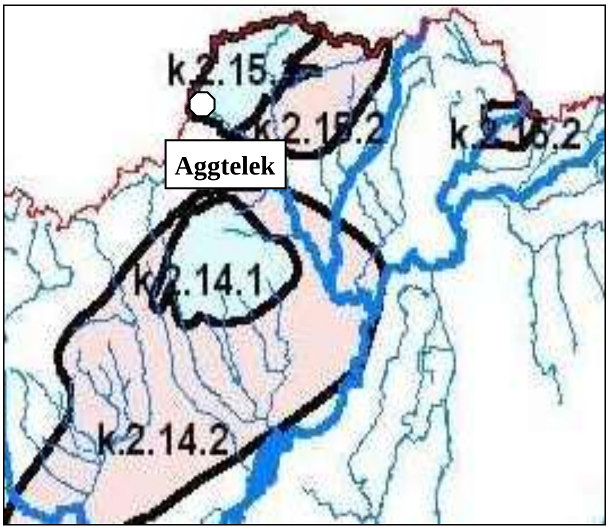


Fig. 2.1.17 Proposal of pre-Quaternary groundwater bodies delineation, categories with analogical type, surface watershed boundaries not included [Kullman et al., 2004] (Legend: 1: mostly karst fissure waters; 2: Fissure waters in the karst fissure rocks; 3: porous rock water; 4: Fissure waters in neovulcanites)
Fig. 2.1.18 Water bodies in the North-Eastern region in Hungary, in karstic aquifers [Simonffy, Nov. 2003.] (Legend: K2.14.1. Bükk Mountains; K2.14.2. Thermal karst attached to the Bükk Mountains; K2.15.1. Aggtelek Mountain, K2.15.2 Thermal karst attached to the Aggtelek Mountain; K2.16.2 Sárospatak thermal karst)

2.5.6. Soil cover

The examination of soil cover is important for infiltration assessment. The soil map of ***Hevesi and Kocsis [2003]*** gives information regarding the soil structure of the entire study area ***(Figure 2.1.19)***. The FAO soil types ***[European Soil Bureau, 1998]*** are shown on ***Figure 2.1.20,*** based on the information coming verbally from ***Endre Dobos, 2004***. Both maps clearly show that the most typical soil cover is the rendzina on the study area.

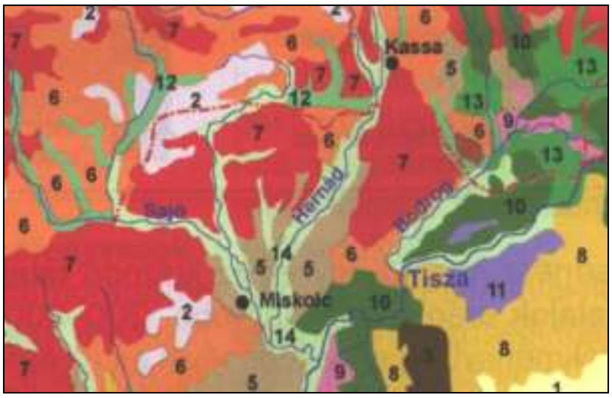


Fig. 2.1.19 Natural soil cover on the study area [Hevesei, Dobos, Elekes in: Hevesi and Kocsis, 2003] (Legend only applies to our study are: 2: Rendzina, 7: brown forest soil with clay illuviation)

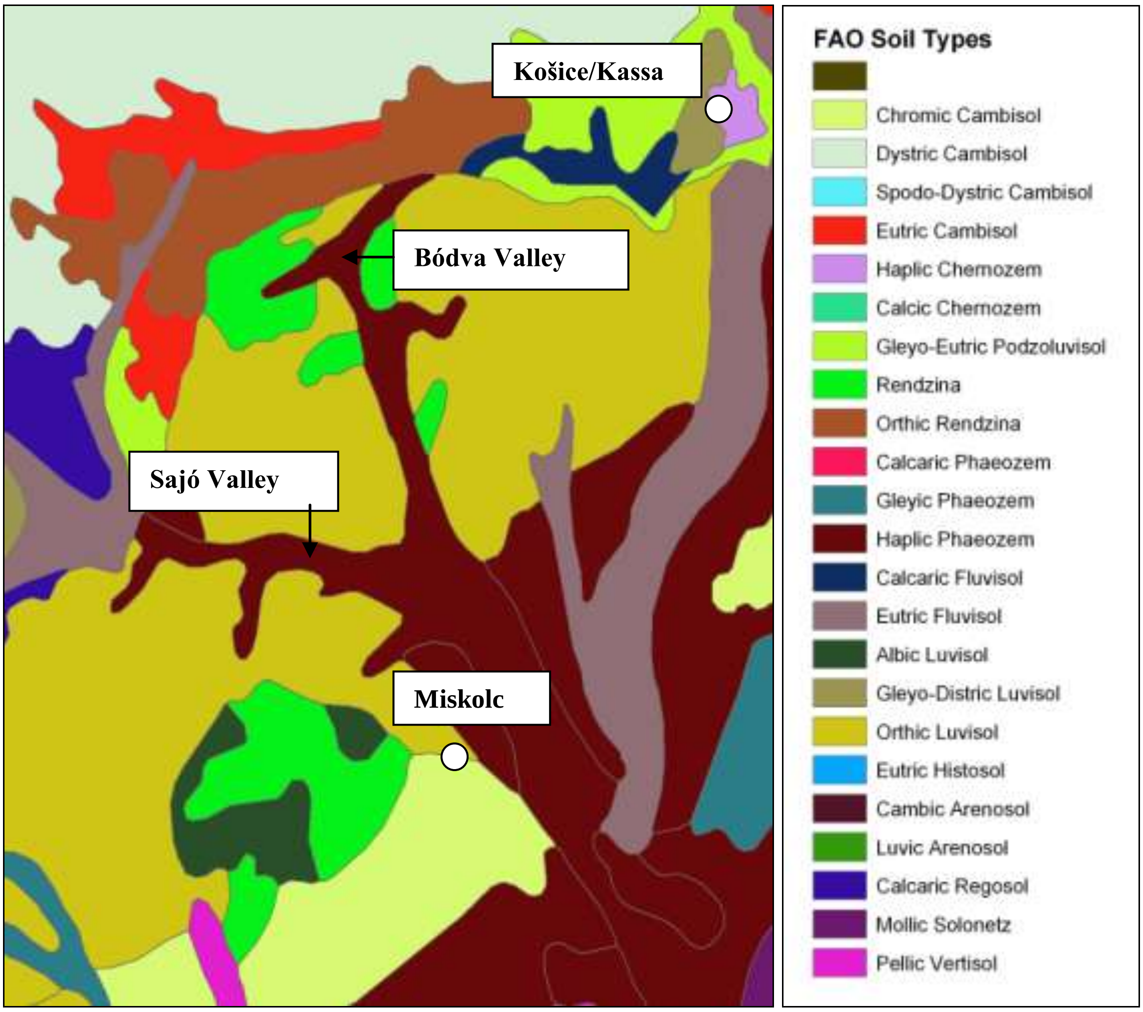


Fig. 2.1.20 FAO Soil types [EUROPEAN SOIL DATA BASE, VERSION 1, 1998]

2.5.7. Flora

The examination of the flora and vegetation is important for the evaluation of infiltration and evapotranspiration. Based on the information coming verbally from and by the publications of ***Dobos et al., 2000; Dobos, 2003,*** the ***Figure 2.1.21a,b,c*** show the relative values regarding the biomass, based on satellite images of August 2000. Both maps clearly show that intensive vegetation is the most typical for the study area, but its quantity varies (shown in different shades of blue).

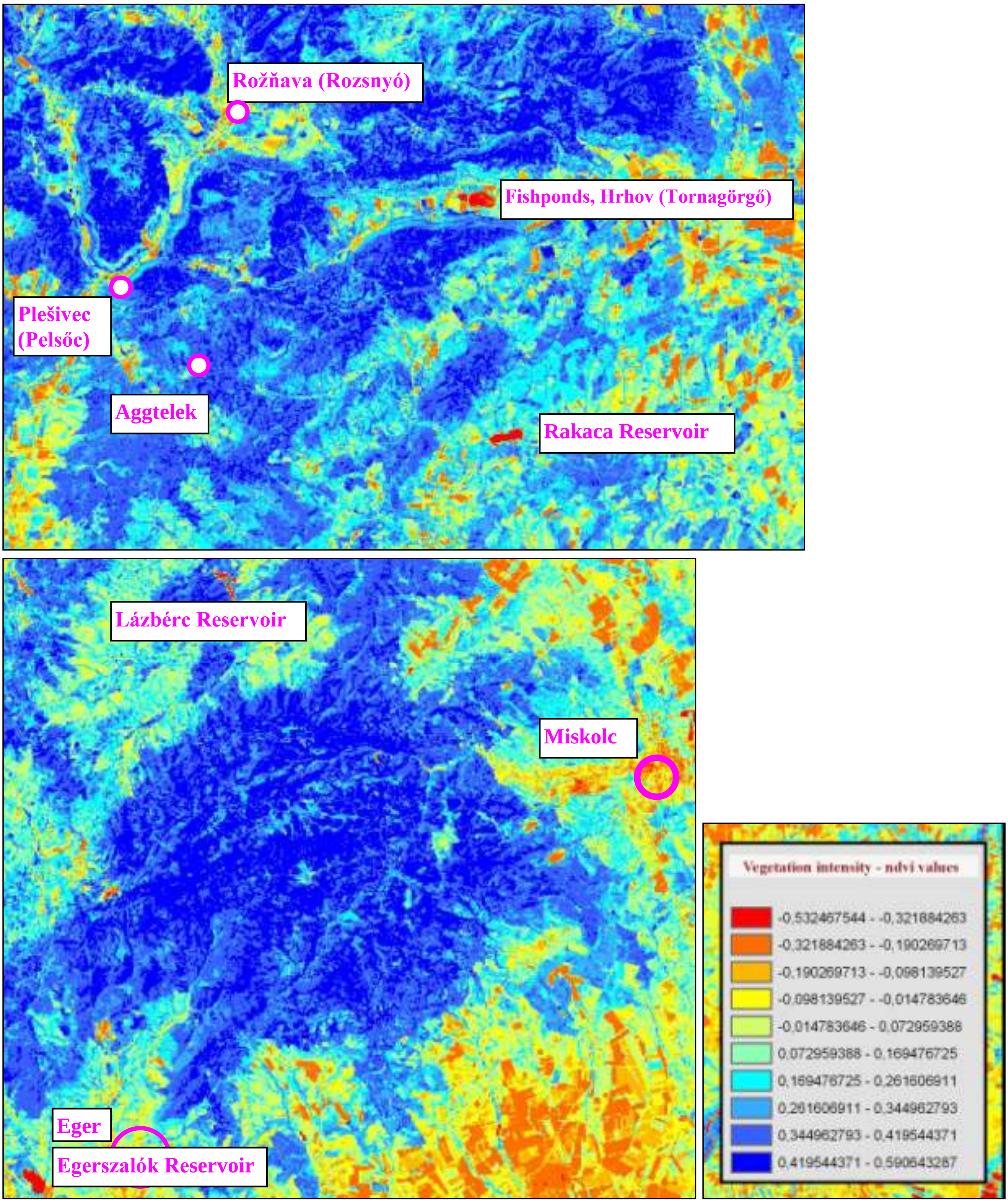


Fig. 2.1.21a,b,c. Vegetation intensity on the study area – derived from satellite images, Aug. 2000. [Dobos, 2004]

2.6. My on-site data collection

2.6.1. Precipitation

Precipitation data collected monthly from the entire area of Bükk Mountains (23 sites) are at our disposal. The major part of the data is starting from the year of 1950 until today; the smaller part of the data is from 1938. The precipitation data collected daily originate from Jávorkút, 700 m a.B.s.l., collected between 1971 and 2001. Before the data collection started at Jávorkút, the precipitation measurement site used to be at Bánkút (855 m a.B.s.l.). Since 1999, the measurements are continuing at this site again. (I have data from both sites overlapping the same 3-year period. With little correction that ensures continuous data flow.)

In order to get the most exact results in the Bükk Karst Water Level Monitoring program, I established a meteorological station at Rejtek (545 m a.B.s.l.) in 1993. The data of this station can be used any time by applying the correction mentioned above. (This data qualifies as own data). ***Figure 2.2.1*** shows all three measurement sites ***[Lénárt, 1997c, 2001 ; Lénárt et al., 2002]***.

2.6.2. Bükk Karst Water Level Monitoring

Karst water levels and temperatures have been recorded systematically since 1992, by using DATAQUA electronic measurement device. (The Radon containt of the karst water was continuously measured in one measurement site. Presently the conductivity is being recorded at another site.) All together we had 41 measuring sites ***(Figure 2.2.1)***. At January 1, 2004, we had 22 sites. (The numbers of measurement sites are not constant, due to the changes in measuring possibilities and the state of measurement devices, but it shows a growing tendency.) Four sites are part of the national monitoring system. This system works under the supervision of University of Miskolc. The system is being supported both financially, both ethically by the water producers, researching establishments and authorities who has interests in the Bükk and its surroundings. A major part of the field data collection was done by myself, mostly in the beginning and at problematic times ***[Lénárt, 1995a, 1997b,c; 2001, 2002, 2004a,b,c; Lénárt and Orbán, 1993; Lénárt et al., 1995a,b, 1996, 2002]***.

I am collecting production data from the three large water companies. In case of smaller companies I get the data mostly from ÉVIZIG (Water Authority), and they are not too accurate. The following table is the summary of those data between January 1993 and December 2004. ("MIVÍZ" = Waterworks of Miskolc; "HMV" = Ww of Heves county; "ÉRV" = Ww of North Hungary; "smaller Ww" = "small" Ww of Zsóry, Bogács, Berva, Húsipar, Egyetem)

"MIVÍZ"	**244 439 000 m^3**	**(72.02 %)**	**1 697 500 m^3/month**	**56 580 m^3/day**
"HMV"	**43 110 000 m^3**	**(12.71 %)**	**299 400 m^3/month**	**9 980 m^3/day**
"ÉRV"	**31 912 000 m^3**	**(9.40 %)**	**221 600 m^3/month**	**7 390 m^3/day**
„smaller Ww"	**19 922 000 m^3**	**(5.87 %)**	**138 400 m^3/month**	**4 610 m^3/day**

Total: 339 383 000 m^3 (100%)   28 281 900 m^3/year   2 356 900 m^3/month   78 560 m^3/day

The following are the production ratios and values for 2004:

"MIVÍZ"	**17 881 400 m^3**	**70.46 %**	**48 990 m^3/day**
"HMV"	**3 389 400 m^3**	**13.35 %**	**9 290 m^3/day**
"ÉRV"	**2 569 700 m^3**	**10.13 %**	**7 040 m^3/day**
„smaller Ww"	**1 539 000 m^3**	**6.06 %**	**4 220 m^3/day**

Total   25 379 500 m^3 (100.0%)   2 115 000 m^3/month   69 540 m^3/day

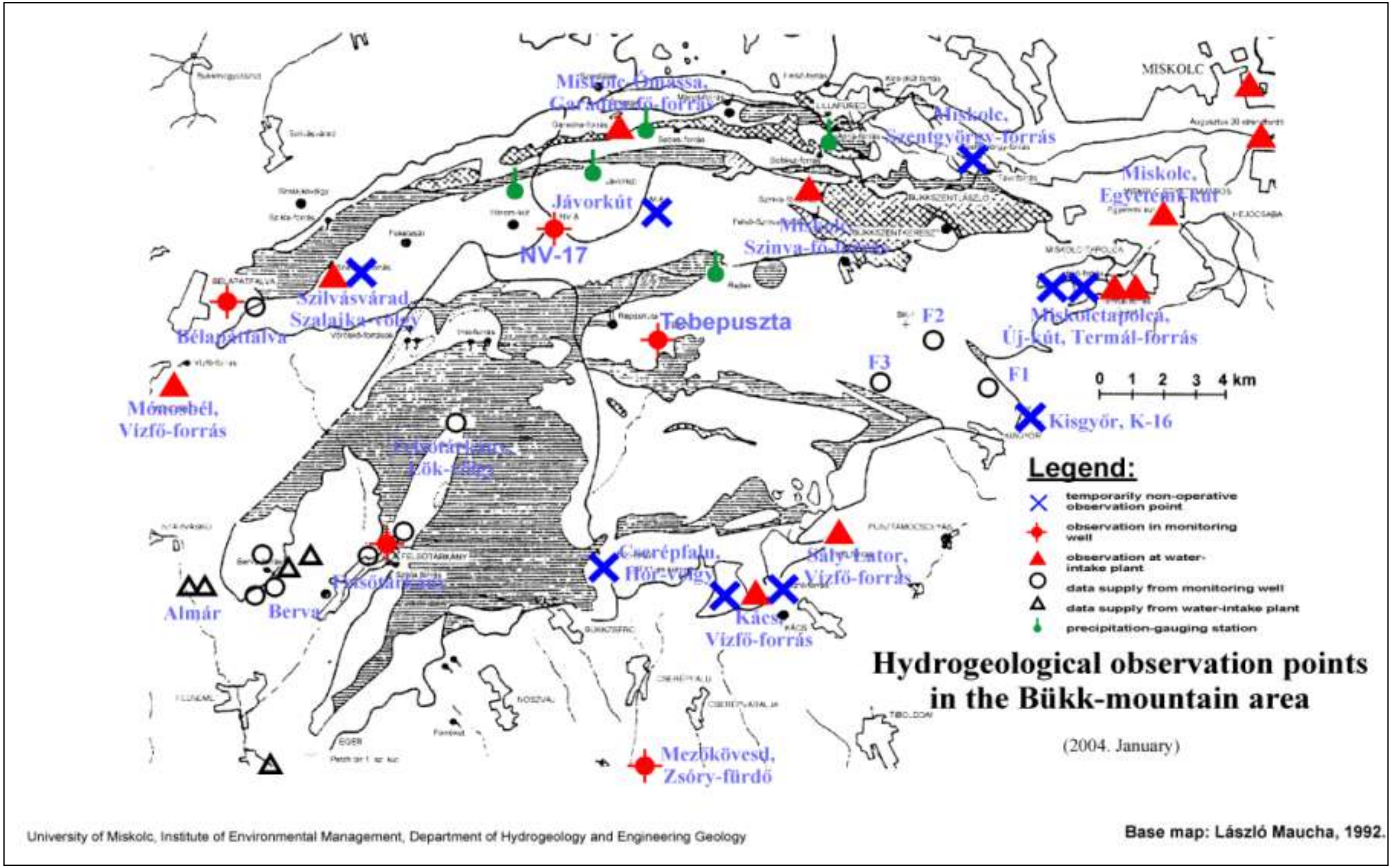


Fig. 2.2.1 The sampling sites of the karst water level monitoring network in the Bükk [Original, 2004a,c] Legend: empty: karstic rock; full: nonkarstic, impermeable rock

2.6.3. Measurement of dripping water discharge in caves (cave drip-measurements)

This measurement determines the amount of water discharge in one time-interval. I myself completed a measurement session between 1971 and 1978. In the Létrási Vizes cave of the Bükk measurements were taken from six different sites every weekend (Friday, Saturday, Sunday) in this timeframe ***(Figure 2.2.2)***.

In 1982, I renewed the above-mentioned session, completed it with 3 new sites (19-20-21), so until 1993 I collected the data from 9 sites, but now only once in a month. This decision based on previous experience. (The measurement sites are between 13,5 m and 140 m below the surface. The furthest site is 750 m from the cave entrance. So a single measurement session means a 4-hour duration and 1300 m long underground trip for a team of 2 or 3 persons, in classic cave surroundings ***[Lénárt, 1974a,b, 1977, 1978, 1980, 1981, 1983a,b, 1986a,b]*** .)

Further drip measurements took place in the Szent István cave of the Bükk between 1989 and 2003, with 5 measurement sites, and in the Béke cave (Aggtelek Karst) between 1996 and 1997, with 4 sites. The data were collected once in a month ***[Lénárt, 2003]***.

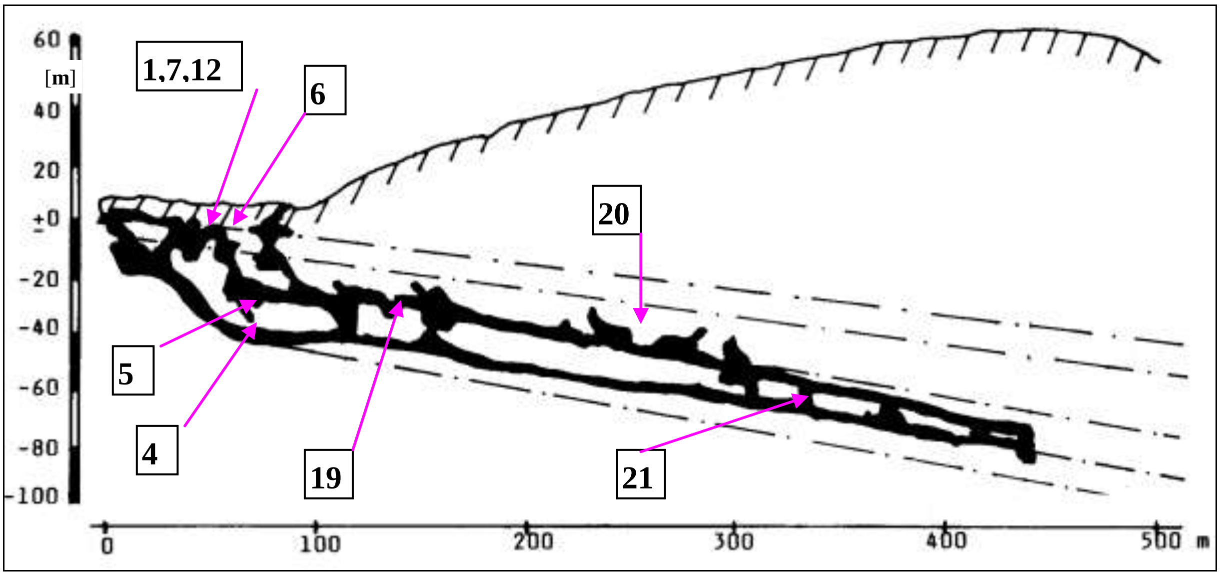


Fig. 2.2.2 The dripping water measurement sites in the Létrási Vizes cave (SW-NE vertical view; the length and height compared to the natural entrance of the cave.) [Original, 1986]

2.6.4. Systematic measurements of Radon in springs and caves

Between 1983 and 1995 a Radon measurement session was accomplished. The sites were wells, springs and in-cave waters of the Bükk Mountains. The collection of the data happened monthly. The device used was an LR-115 (by Kodak) by integrating nuclear track detectors.

The ATOMKI of Debrecen (Institute of Nuclear Research of the Hungarian Academy of Sciences) allowed me to use their devices. I myself changed the necessary films on the sites; the laboratory work and analysis were done by them. ***Figure 2.2.3*** shows the overview map of the measuring sites and the most typical measured values. (Details in the chapter „Results of research***" [Hakl et al., 1989, 1993; Lénárt, 1991; Lénárt et al,. 1990, 1992, 1993; Somogyi and Lénárt, 1986a,b]***.)

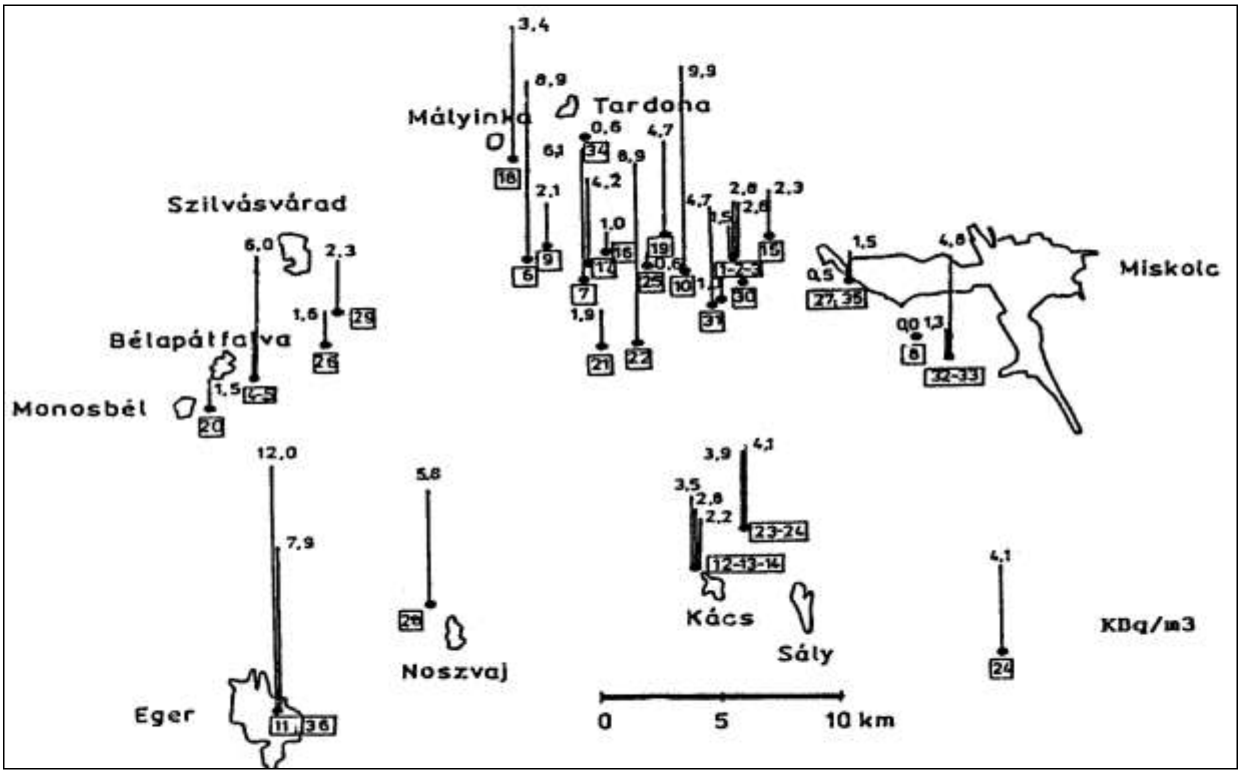


Fig. 2.2.3 Locations and values of Radon measurement in the Bükk Mountains [Original, 1991]

2.6.5. Monitoring the condition of cave cleanness and cave cleaning

In order to diminish the possibility of karst water contamination, systematic monitoring of the caves and their cleaning is necessary. Between 1998 and 2004, 9 different monitoring session took place to check the cleanness of the caves of the Bükk. These surveys were assigned to us by authorities and establishments researching in the Bükk.

761 caves got different qualifications from the contamination point of view. 115 caves were examined during field trips. 94 caves were qualified as potentially dangerous for the karst water (and water company). The conditions of these caves were monitored 1-3 times in the near past ***[Lénárt, 1998; Lénárt and Takácsné, 2002]***.

Figure 2.2.4 shows the year 2004 results of the systematic monitoring of the caves within the boundaries of the protected zone of Miskolc. The work done in the caves are explained through the legend.

Figure 2.2.5 shows the results of a simplified monitoring. Here we can find mostly smaller caves that are not being visited by too many people; therefore the contamination level of these caves is much lower compared to the situation presented on the previous figure.

2.6.6. Assessment of contamination at the sites in the East Bükk

In the Eastern part of the Bükk (the hydrogeological well-head protection zone of the Miskolc water company) a complex assessment took place in 1996 within the frames of the country-wide groundwater protection and assessment program ***[Lénárt, 1996]***.

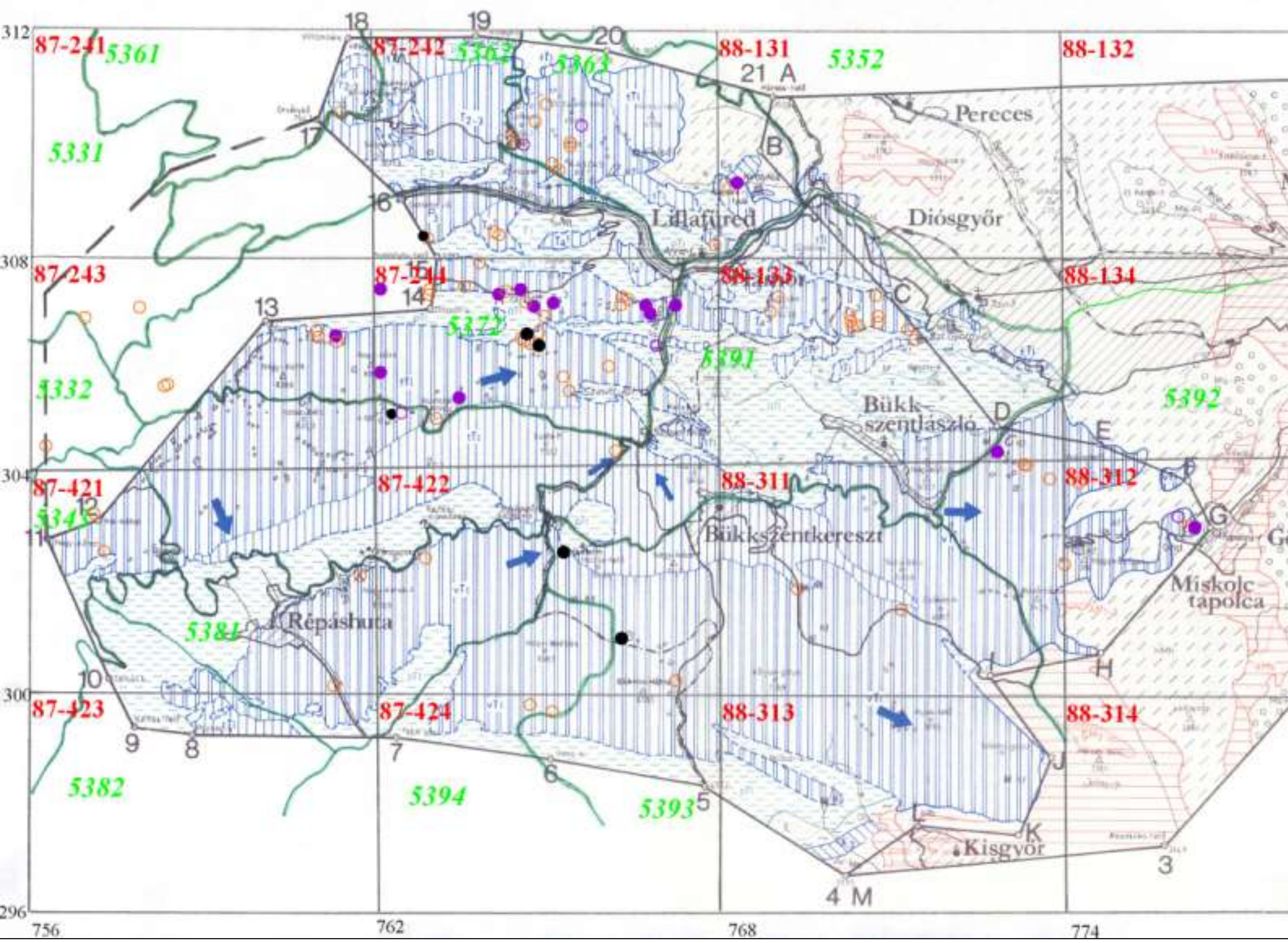


Fig. 2.2.4 Locations of cave cleanness program and cave cleaning in the east part of Bükk Mountains [Original, 2004]

87-241: maps of M = 1 : 10.000;

4M-21A-4M: The free-surface protected zone of the springs that are partaking in the water supply for Miskolc;
▬ ▬ : The suggested extension of the protected zone;
1-4M-21A-1: The under-pressure protected zone of the springs that are partaking in the water supply for Miskolc;

5361: Cave cadaster units;

○ *: The cave examined was clean at the examination;*
○: *The contaminant was removed from the cave;*
● *: The contaminant was not completely removed;*
● *: The entrance of the cave is clogged up*

Hydrogeological information:
(blue): karstic rocks;
(blue arrow): flow direction of karst water

(green): not karstic rocks that give their water to the free-surface karst; (black): non-karstic aquifers; (red): non-karstic aquifers

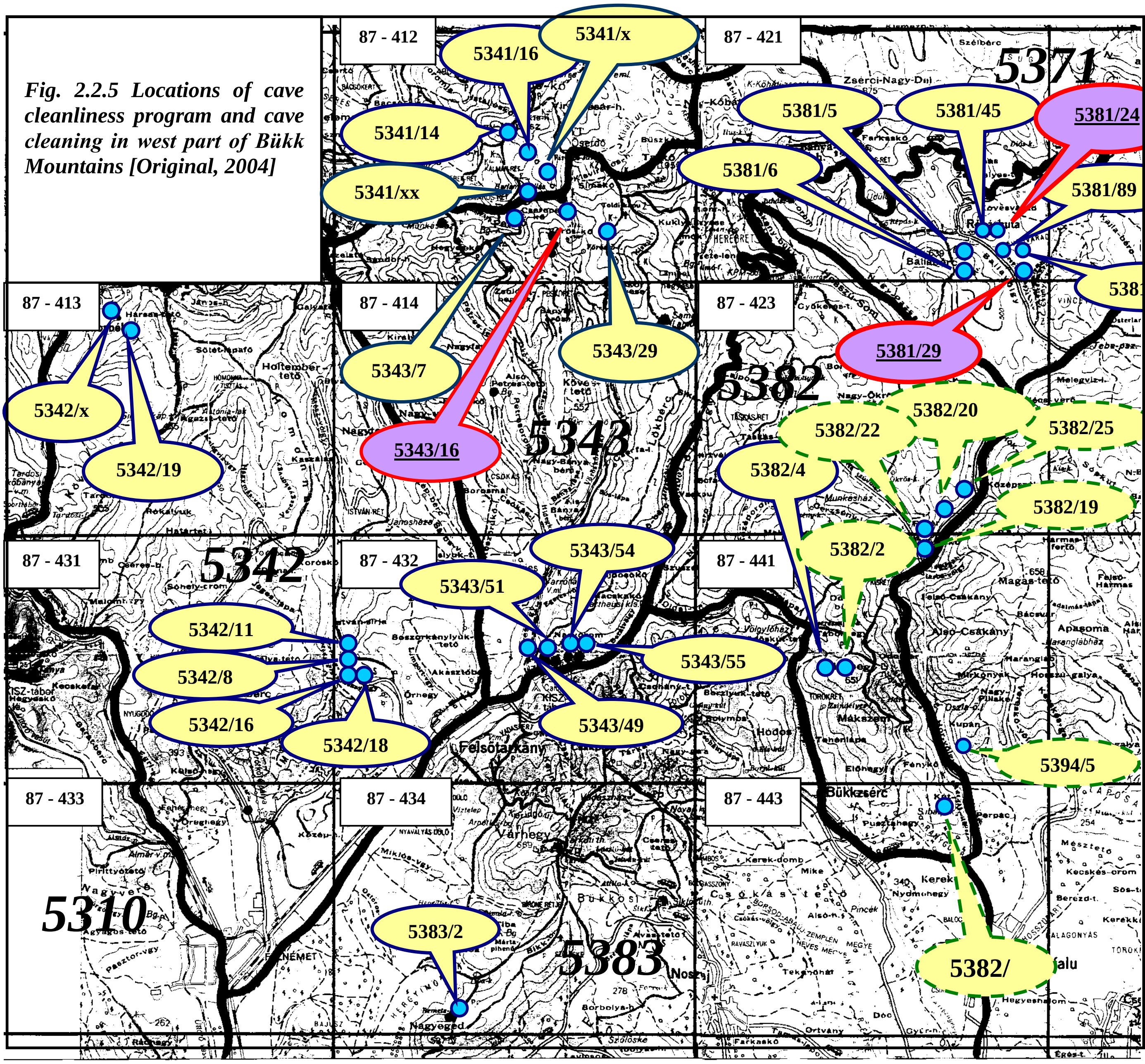


Fig. 2.2.5 Locations of cave cleanliness program and cave cleaning in west part of Bükk Mountains [Original, 2004]

3. The results of my environmental research

3.7. Changes in precipitation

The economical and ecological water resources basically originate from precipitation, so its thorough and detailed examination is very important. Of course, the ecological water resources also become „society's demand" on the long run. The results of this analysis have been published continually ***[Lénárt and Orbán, 1993; Lénárt et al., 1995a,b, 1996, 1997, 2002; Lénárt, 1997b,c, 2001, 2002, 2005a,b]***.

Table 3.1.I. gives a summarized overview of the precipitation in the Bükk Mountains. About 80 % of the precipitation data that had been collected at Jávorkút can be accepted as precipitation average data for the entire Bükk. (The data collected at Rejtek is very similar to this, about 84-86 % of the values measured at Jávorkút. The data coming from Bánkút is about 93-95 % of the Jávorkút data.) The evaluation time period had been determined by he numbers shown on ***Figure 3.1.1***, based on own research.

The Jávorkút data have been replaced with the corrected Bánkút data since July 2001, due to technical reasons. (The correction equation is: Monthly Bánkút Value *1.062=Monthly Jávorkút Value.)

Table 3.1.I.

Jávorkút average precipitation data (Starting average = 1960-2004)

Time period	Precipitation [mm] Hydrological winter season		Precipitation [mm] Hydrological summer season		Precipitation [mm] Calendar year	
	average	difference from average	average	Difference from average	average	Difference from average
1960-2004	326,7		490,7		817,3	
1961-2004	327,6	+0,8	489,5	-1,2	814,3	-2,9
1971-2004	313,9	-12,8	502,0	+11,3	813,2	-4,0
1981-2004	313,5	-13,2	492,8	+2,1	803,3	-14,0
1992-2004	345,3	+18,6	551,7	+61,0	892,7	+75,5
1961-1970	374,0	+47,3	446,9	-43,8	818,1	+0,8
1971-1980	314,8	-11,9	524,2	+33,5	837,1	+19,8
1981-1991	275,9	-50,8	423,2	-67,6	697,5	-119,7
1992-2004	345,3	+18,6	551,7	+61,0	892,7	+75,5

As the total precipitation values by calendar year column shows, four times in the last 44 years were very low precipitation year, in about every 10-11 years. (From environment protection and water resources aspect, the most important is to evaluate the low precipitation periods.) ***Figures 3.1.1-3.1.3*** clearly show that the lowest and the highest values in the last 44 years occurred in the last 12 years, so the fluctuation is great. This fluctuation is being introduced in ***Table 3.1.II***, including the evaluation of hydrological seasons. The values clearly show both in the hydrological seasons, in the calendar year column. The extremely dry and extremely wet weather took place in the evaluated period.

Looking at the hydrological seasons, it can be stated that in the same given year, the winter and summer precipitation changes as many times as its opposite. In addition to this, when the amount of precipitation changes to the same direction, in both cases there are as many dry periods as wet periods ***(Figures 3.1.4-3.1.5)***. So I can not detect any clear tendency in the distribution of precipitation.

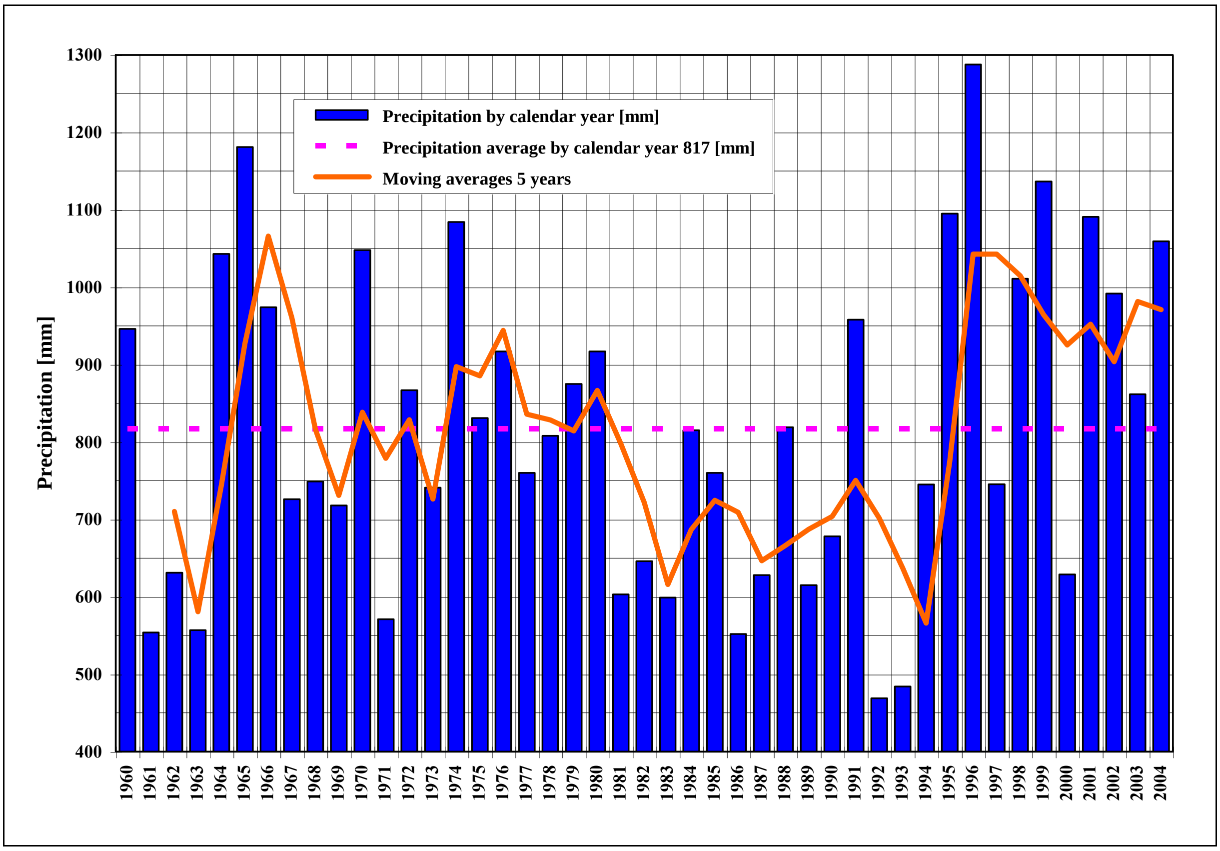


Fig. 3.1.1 Precipitation by calendar year (Bükk, Jávorkút) [Original, 2005]

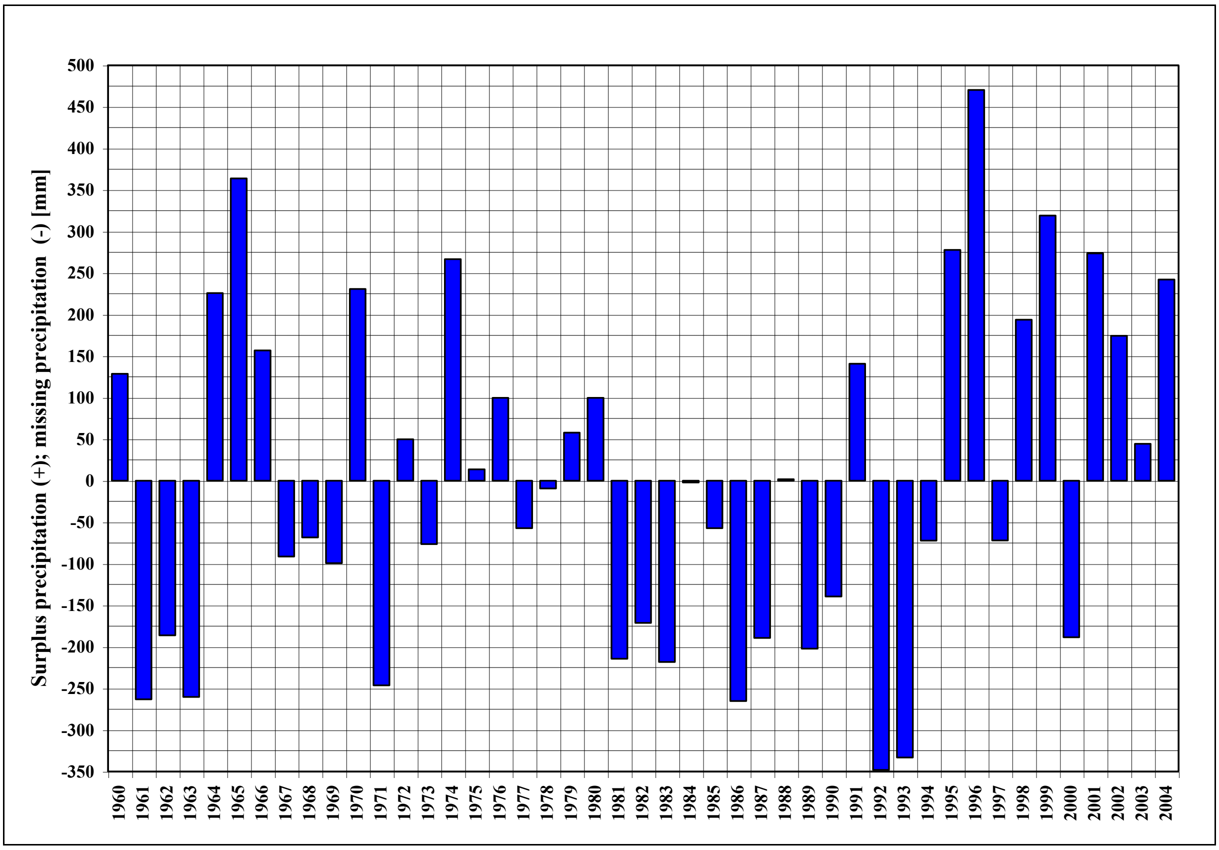


Fig. 3.1.2 Deviation from precipitation average by calendar year (Bükk, Jávorkút) [Original, 2005]

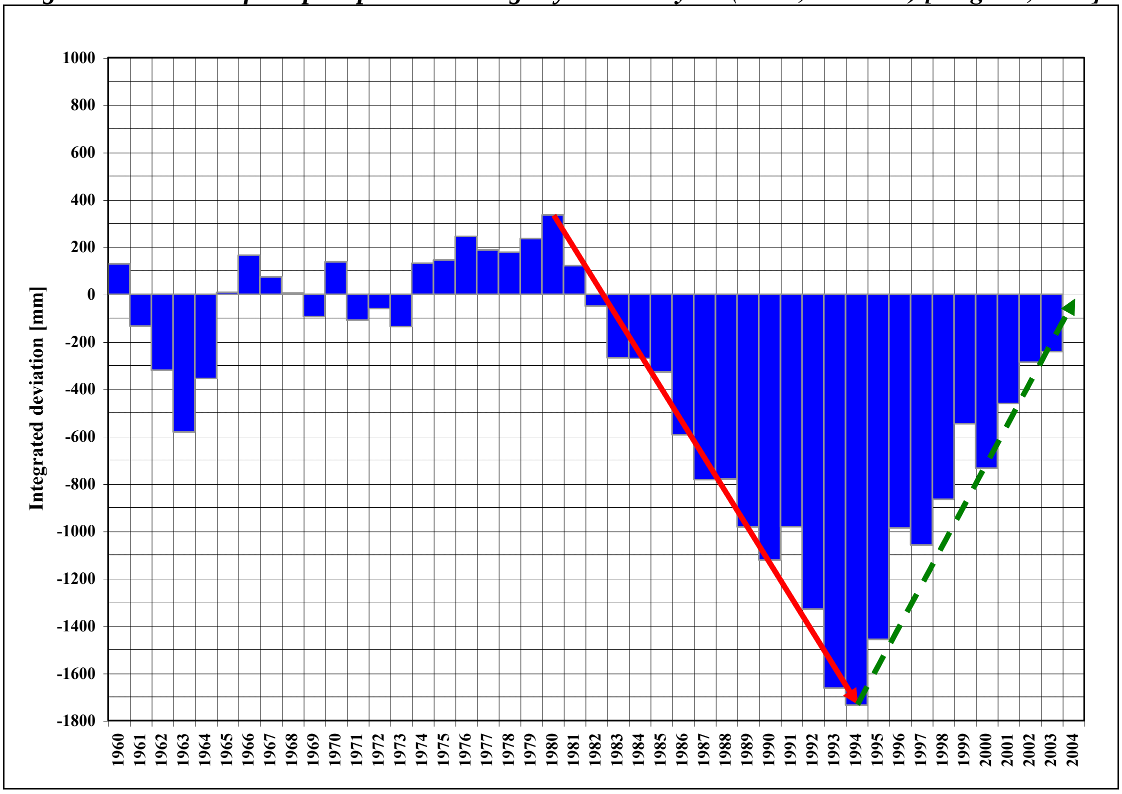


Fig. 3.1.3 Integrated time series of the deviation from precipitation average by calendar year (Bükk, Jávorkút) [Original, 2005]

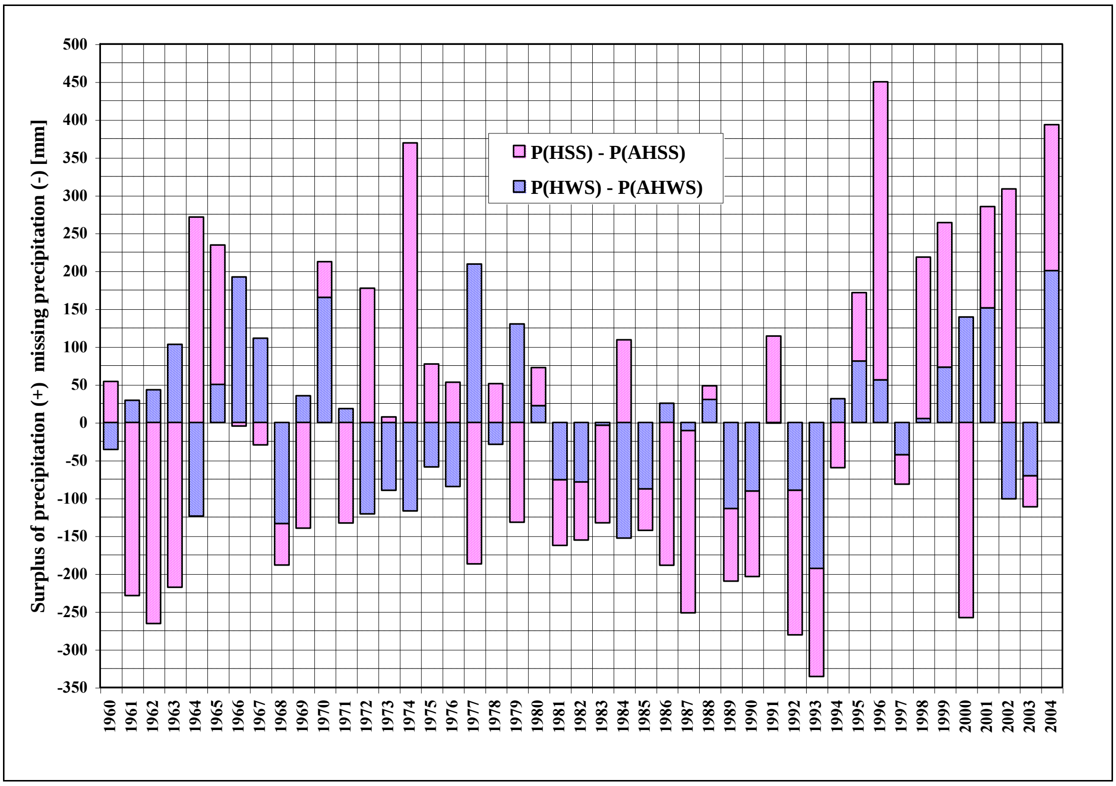


Fig. 3.1.4 Deviation from precipitation average by hydrological season half-year term (Bükk, Jávorkút)

(Legend: P=precipitation; H=hydrological; S=summer; S=season; A=average; W=winter; average of hydrological winter season 1960-2004: 327 mm; average of hydrological summer season 1960-2004: 491 mm) [Original, 2005]

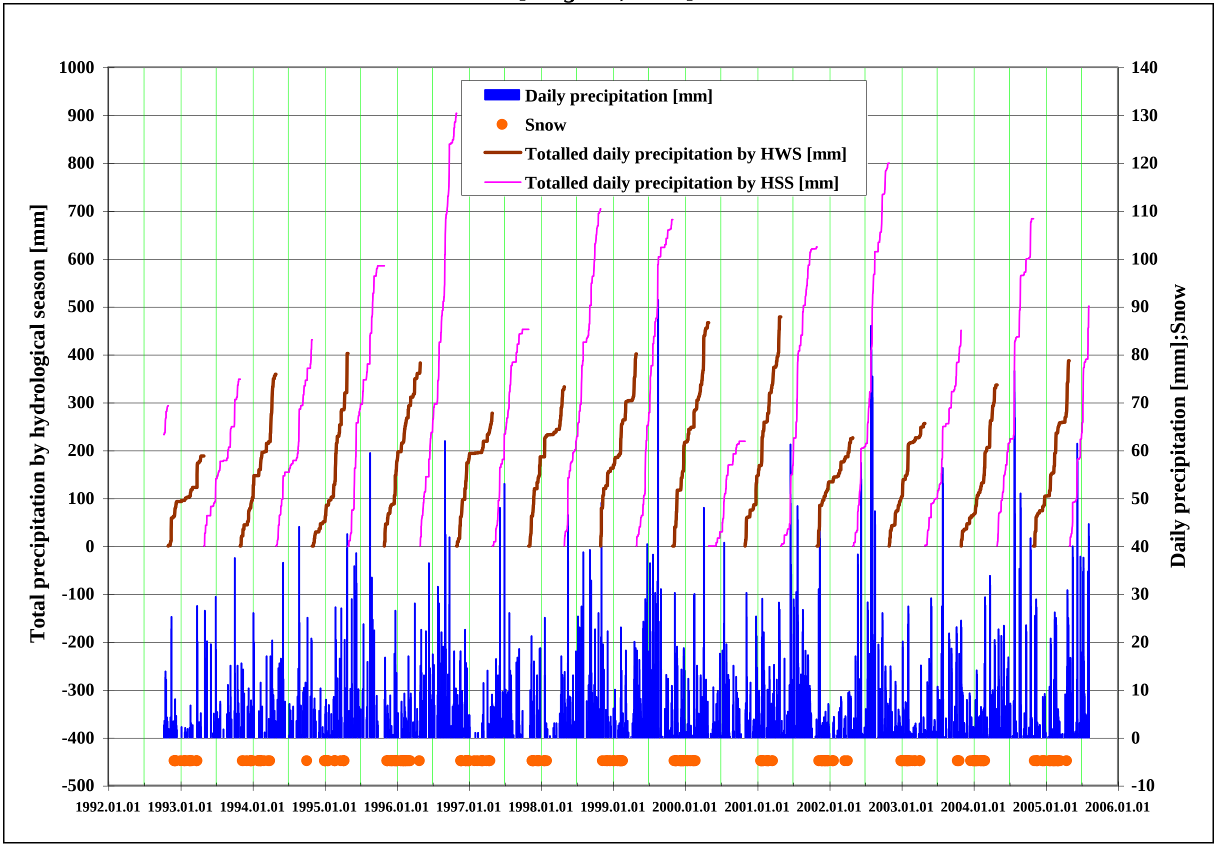


Fig. 3.1.5 Summarized daily precipitation by hydrological season half-year term (Bükk, Jávorkút) (Legend: H=hydrological; S=summer; S=season; W=winter) [Original, 2005]

Table 3.1.II.

Overview of the precipitation conditions compared to the average between 1960-2004, Jávorkút

Year	Hydrological winter season	Hydrological summer season	Calendar year
1992	Significantly lower than average	Extremely dry	Extremely dry
1993	Extremely dry	Extremely dry	Extremely dry
1994	Little higher than average	Dry	Little lower than average
1995	Little higher than average	Little higher than average	Significantly higher than average
1996	Little higher than average	***Extremely wet***	***Extremely wet***
1997	Little lower than average	Little lower than average	Little lower than average
1998	Average	Significantly higher than average	Significantly higher than average
1999	Little higher than average	Significantly higher than average	Significantly higher than average
2000	Significantly higher than average	Extremely dry	Significantly lower than average
2001	Significantly higher than average	Significantly higher than average	Significantly higher than average
2002	Significantly lower than average	***Extremely wet***	Significantly higher than average
2003	Significantly lower than average	Little lower than average	Significantly lower than average
2004	Significantly higher than average	Significantly higher than average	Significantly higher than average

Using the 5 points moving average method to evaluate the precipitation values both by hydrological seasons, both by calendar year, permanent lower than average values were detected:

- In case of calendar years between 1981-1995 (15 years)
- In case of hydrological summer seasons between 1979-1995 (17 years)
- In case of hydrological winter seasons between 1984-1997 (14 years)

When evaluating the summarized precipitation changes, permanent precipitation reduction was detected:

- In case of calendar years between 1981-1994 (14 years)
- In case of hydrological summer seasons between 1977-1994 (18 years)
- In case of hydrological winter seasons between 1981-1993 (13 years)

Between 1960-2004 the annual amount of precipitation was greatly changeable in the Bükk Mountains. Significantly lower than average amount of precipitation was detected between the end of 1970 and the middle of 1990.

It is very interesting that the decreasing water amount originating from less precipitation falls into the same time period with the significant growing of the ecological water demand from the area. It meant that bank-filtered groundwaters from the Sajó-Hernád valley had to be supplemented to the water resources to meet the demands that karst water was not able to satisfy. A significant amount of water supplier system was built at that time that later became unused due to the diminished water demand. (More on this later.)

I will deal later with the part of precipitation that reaches karst water.

3.8. Estimation of evapotranspiration

All three areas are open karst covered by thin, several dm of rendzina soil that influences the karstic infiltration conditions.

Soil characteristics in the Bükk and Aggtelek Karst:

- carbonate soils,
- the thickness of the fertile soil is 20-40 cm,
- organic content is 200-300 tons/hectare,
- they belong to the extreme water management types.

As ***Figures 2.1.19 and 2.1.20*** show, all three areas has approximately the same soil type in that thickness that is relevant for assessing evapotranspiration, so it can be stated that they are the same type.

Assessing the amount of vegetation in the study areas is also very important in terms of the evapotranspiration. (Its the most problematic part of the hydrological water balance equation in karstic areas.) The amount of afforestation is critical.

The amount of afforestation is not depending on the content and the thickness of the soil in this area, but depends on the height above sea level, on the altitude and on the human interaction.

The vegetation index (NDVI) ***[Asrar et al., 1984]*** based on satellite imagery of ***Figure 2.1.21a,b,c*** clearly shows the major vegetation in the Bükk Mountains. There is less vegetation on the Slovak Karst, and even less on the Aggtelek Karst. It means that the evapotranspiration in the hydrological water balance equation will be the highest in the Bükk, will be less in the Slovak Karst, and least in the Aggtelek Karst ***[Kullman, 1990; Tomlain, 1997]***. (To determine its value we need further surveys.)

In case of the Bükk, these numbers try to show the amount of evapotranspiration between November 1, 1993 and December 31, 2004. Starting data:

- Map of karst water level monitoring network in the Bükk ***(Figure 2.2.1)***
- Water level changes: changes in the Nv-17 (=Nv-8) for the entire Bükk
- The starting „0" is the value of the Nv-17 water level monitoring well at November 01, 1993, at the „drought of the century" (-256.92 m under field level, 522.98 m a.B.s.l.)
- The range of rock able to hold the karst water resources: 207 km^2
- Precipitation aquifer is 230 km^2 (The disregarded non-karstic area is 23 km^2)
- Porosity 0.75 %
- Typical precipitation: 0.8 times the Jávorkút amount
- Amount of spring discharges: 75 % of the production
- Water reaching into the detrital aquifers through the edges: 10 % of the production

The hydrogeological water balance equation between 1 November, 1993 and 31. December, 2004 is the following, according to the above statements and considering the monthly averages and totals:

INPUT:	
Total precipitation:	**1 904 511 000 m^3**
OUTPUT:	
Production:	**316 830 000 m^3**
Overflow water:	**237 623 000 m^3**
Passed water:	**31 683 000 m^3**
Output total	**586 136 000 m^3**
Water stored (Dec 31, 2003):	**10 610 000 m^3 (n=0.75 %)**
Infiltration %:	**31,33 % (n=0.75 %)**

According to the Jósvafő analogy, in the Bükk the runoff is about 5-7 % for the entire mountain.

Based on my own research the evapotranspiration in the Bükk is about 61-64 % that significantly changes with time.

3.9. The results of infiltration assessment

3.9.1. Infiltration features of the soil cover

The precipitation either percolates through the soil as local infiltration or falls under the surface by sinkholes. The local infiltration mainly depends on the characteristics of the soil cover.

The thickness of the soil cover and the infiltration conditions were evaluated above the Létrási Vizes cave in the Bükk ***[Lénárt, 1974a,b, 1983b, 1986a]***. (This evaluation was necessary because of the drip-measurements in the cave.) The soil cover here is several dm thick, its water conductivity equals to that of the mud – silty mud. (Its soil characteristics were discussed above.) It means an infiltration factor of 10^{-3}-10^{-5} m/s, slightly better on the topmost part of the soil where the vegetation's roots are.

Based on the in-cave drip measurements in the Létrási Vizes cave, I found the 140 m thick limestone layer's infiltration factor (equivalent value) here is about 10^{-2}-10^{-3} m/s.

The soil's water conductivity has one magnitude smaller value than the conductivity of the well-karstified Triassic (Anisian) limestone (infiltration equivalent value). So the amount of the infiltrated water is being determined by the characteristics of the several dm thick soil cover.

3.9.2. Infiltration conditions in the epikarst

Many researchers tried to determine the infiltration factor in limestones with the help of in-cave drip-measurements. I will not discuss this in detail, but I would like to mention three examples for different methods of drip-measurement:

- Many different kind of drip-measuring device was developed and used in the Aggtelek Karst (On ***Figure 3.3.1*** I show an automatic drip-measuring device.)
- Vessels with few m^2 opening being used in Slovenia and dripstone groups
- In many cases the amount of water collecting in a vessel under the dripstone gives the yield value of the dripstone

The in-cave drip-measurements were started in Hungary in 1955 by Hubert Kessler ***[Böcker, 1975]*** in the Szent István cave of the Bükk. The following authors has published material regarding in-cave drip-measurement: ***Szabó, 1963; Gádoros, 1960, 1966; Müller, 1973; Böcker, 1974, 1975; Lénárt, 1974a,b, 1977, 1978, 1980, 1981, 1983a,b, 1986b, 2003; Kessler, 1975; Maucha, 1990***.

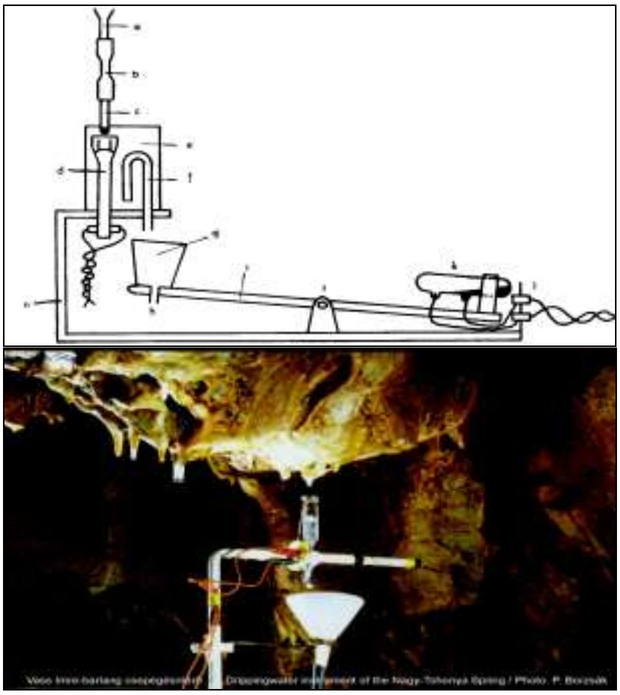


Fig. 3.3.1 Measurement of dripping water in the Vass Imre cave, Jósvafő [Gádoros, 1960, 1966; Maucha, 1998]

In the Szent István cave of the Bükk, Hubert Kessler ***[Böcker, 1975]***, and later Szabó and Lénárt had measured the drip yields in a very simple way: a water collecting tank was put underneath the dripping places and at certain time intervals the quantity of water was measured in the tank. (Of course, the more frequent were the measurements the more accurate were the results regarding the intensity of water seeping through the rocks.) ***Böcker [1974, 1975]*** had found that under a certain level of precipitation there is no infiltration at all. (The 5.000 cm^3 drip-yield per measurement phase – 1,7-3,4 cm^3/ hour – was declared free of infiltration in his opinion.) He called this the method of "limiting value of precipitation". Different values were determined by him based on the individual measurement phases ***(Figure 3.3.2)***. Let me note that this principle is very similar to certain precipitation quantities what I call "active precipitation groups". I will talk about it in a little more detail in ***Chapter 3.4.3.2***.

The changes of drip-yields in the St. István Cave can be presented very well by my own measurement results, too, ***(Figure 3.3.3)***. The summarized result of this data will be presented in text in the following.

The locations of in-cave drip measurements stated in papers of ***Lénárt, [1983b]*** and are photographed and shown on ***Figures 3.3.4a,b,c,d***.

The year 1973-74 data of the measurement session can be seen on ***Figures 3.3.5-3.3.6***. Please note that in June of 1973 there was such high amount of precipitation that it caused a serious flood in Miskolc. (The outstanding values can be seen clearly on the chart.)

I had analysed the data of the time period between 1971 and 1978 in other ways as well.

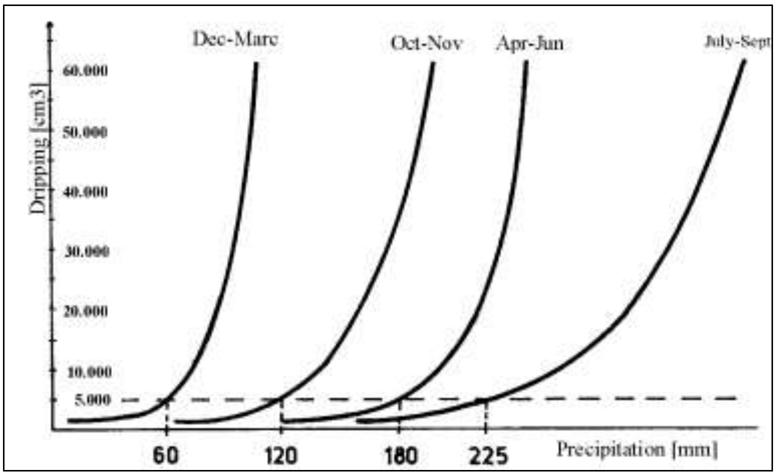


Fig. 3.3.2 Results of the dripping water measurement in the Szent István cave, Bükk Mountains [Böcker, 1975]
(Note: No karstic infiltration or in-cave dripping beneath the level of the broken line - 5.000 cm^3)

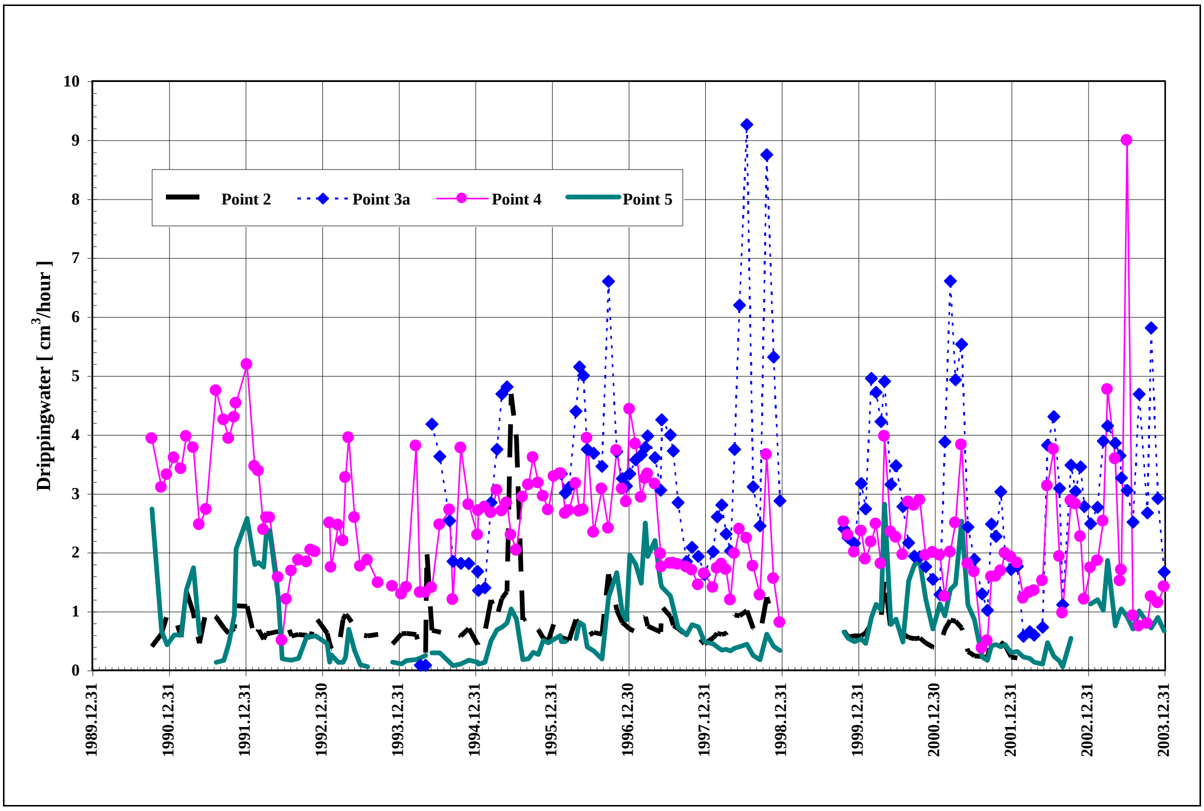


Fig. 3.3.3 Results of the dripping water measurement in the Szent István cave, at four different measuring points, Bükk Mountains [Original, 2003]

Figure 3.3.7 clearly shows that the yield of the dripping points and the active time period is highly changeable. We only had one measurement point where the dripping was continuous all year around. Another point measured a very high amount of yield, and another was active for only a very short period of time.

Analyzing the entire string of data I had found a number of relationships between the precipitation and dripping ***(Figures 3.3.8-3.3.10)***. Let me note that these statements are supported by the changes in karst water level that are shown on ***Figures 3.4.20 and 3.4.64-3.4.65***.

Fig. 3.3.34a,b,c,d Drip-measurement points in the Létrási Vizes Cave [Original, 1973]
(Legend: a: Top of small dripstone, very stable yield, measurement point No. 4; b: water stepping out of creased limestone lithoclasis system, stable yield, measurement point No. 5; c: montmilch stalactite, changing

yield, measurement point No. 12; d: dripstone with corroded end, highly changeable yield, measurement point No. 7)

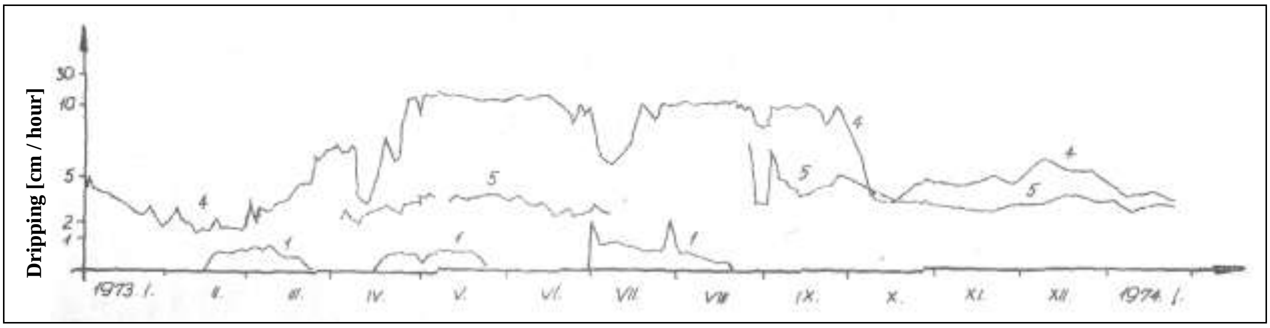


Fig. 3.3.5 Results of the dripping water measurement in the Létrási-Vizes cave, Bükk Mountains, at 1973-74 (Legend: 1, 4, 5: Measuring points, see Figure 2.2.2) [Original, 1983]

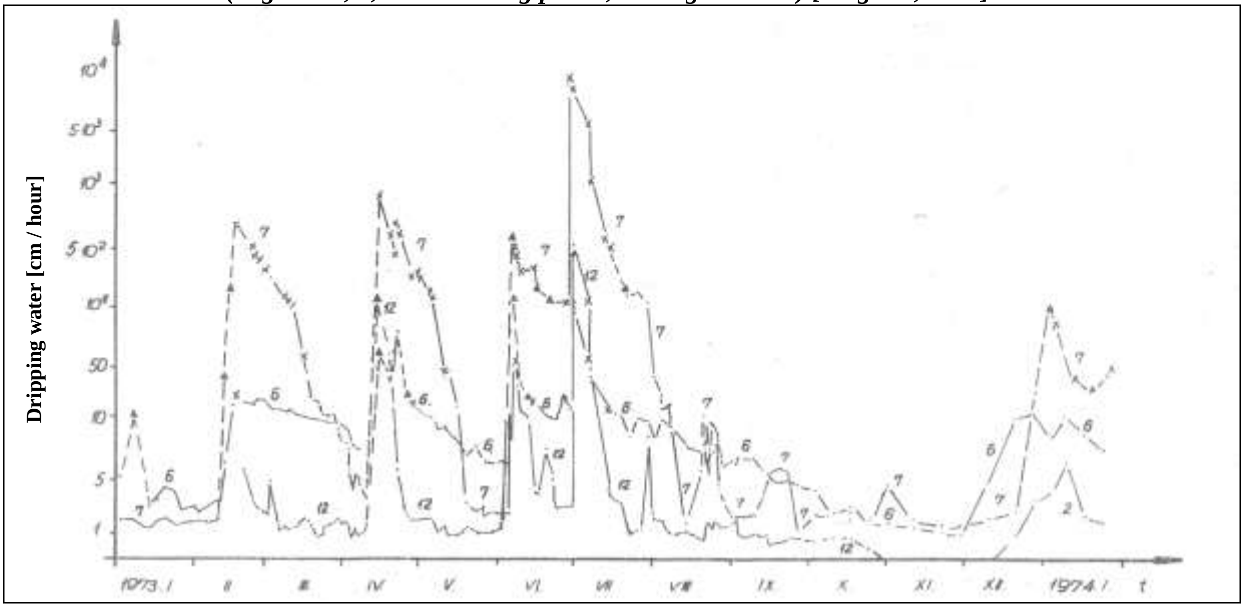


Fig. 3.3.6 Results of the dripping water measurement in the Létrási-Vizes cave, Bükk Mountains, at 1973-74 (Legend: 6, 7, 12: Measuring points, see Figure 2.2.2) [Original, 1983]

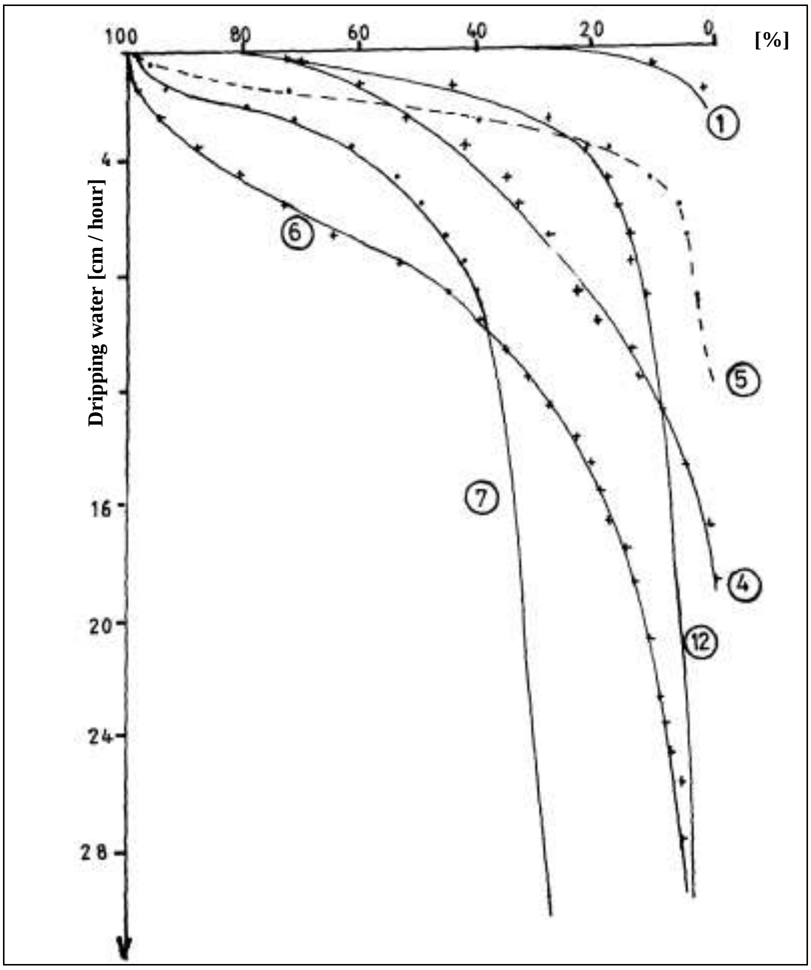


Fig. 3.3.7 Results of the dripping water measurement in the Létrási-Vizes cave, Bükk Mountains, at 1971-78. Persistence of drip-yield (Legend: 1, 4, 5, 6, 7, 12: Measuring points, see Figure 2.2.2) [Original, 1983]

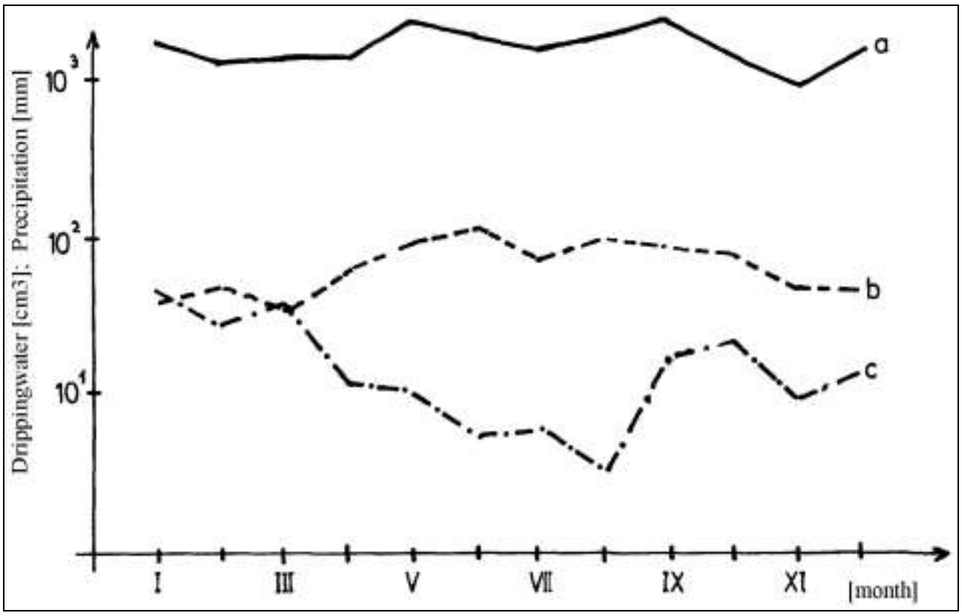


Fig. 3.3.8 Results of the dripping water measurement in the Létrási-Vizes cave, Bükk Mountains, at 1971-78. Average values [Original, 1983] (Legend: a: dripping water; b: precipitation; c: dripping water/precipitation)

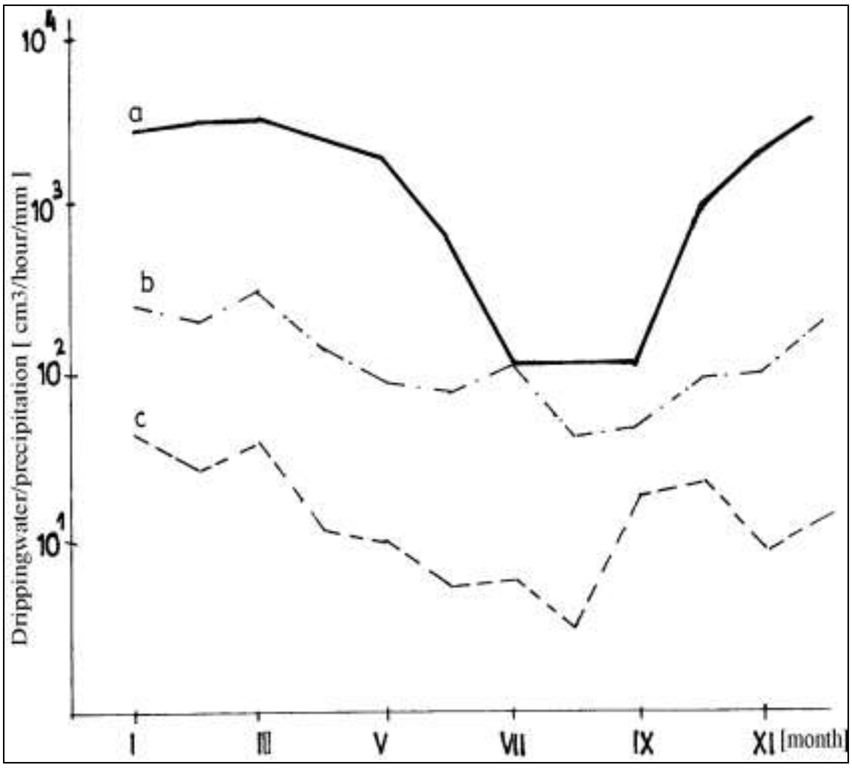


Fig. 3.3.9 Results of the dripping water measurement. The drip-yield changes by the effect of 1 mm precipitation water [Original, 1983] (Legend: a: Szent István cave, by Kessler; b: Létrási-Vizes cave, 1971-79, in the point No. 6, see Figure 2.2.2; c: Létrási-Vizes cave, 1971-79, in the point No. 4, see Figure 2.2.2)

According to my research, the drip-yields are fluctuating greatly with time. Often there is no dripping activity at all. (Naturally the infiltration-free period can be noted only if the measurements and the recording happen often enough. In long infiltration-free periods the conductive ducts of the dripstones could crystallize over, leaving no opening for the water to pass through.)

According to the daily/weekly measurement sessions in the Létrási Vizes cave, the yield ranges between 0 and 1500 ml/hour. (The least fluctuation site was 0-2.9 ml/hour; the greatest was 0-1500 ml/hour.)

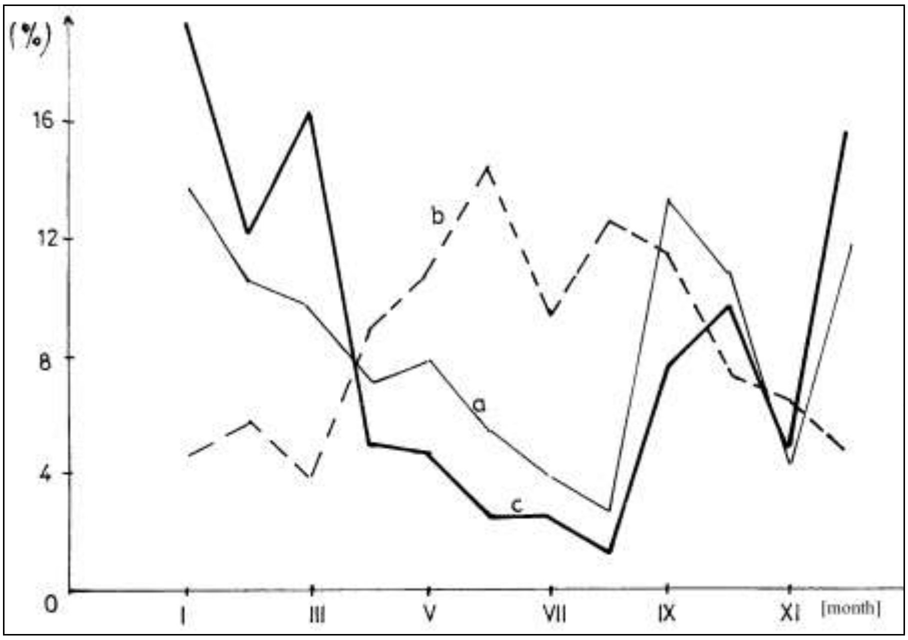


Fig. 3.3.10 Results of the dripping water measurement. The ratio of monthly precipitation and dripping compared to the annual amount, Létrási-Vizes cave, 1971-79 [Original, 1983]
(Legend: a: dripping water; b: precipitation; c: dripping water/precipitation.)

According to the monthly measurements in the very same cave the yields changed between 0.1 and 29.6 ml/hour after filtering through the minimum 40 m thick rock. ***(Figure 2.2.2)*** In case of the Szent István cave, the yield fluctuated between 0.0 and 8.99 ml/hour.

My in-cave drip-measurements offered a great opportunity to follow the physical process of the vertical movements of the water in the epikarst. The physical process of the three phases of the infiltration could be followed at the in-cave, close to the surface measurement sites ***(Figure 3.3.11)***. I also was able to link the movements of the water to the precipitation changes. I noted that after the precipitation the infiltrating water pushes the air front of itself from the joints - three-phase infiltration – therefore 12-15 hours after precipitation the measurement sites recorded increase in the drip yield, 25-50 hours after the precipitation the yield decreased. When only the water remains present – two-phase infiltration – the drip yield gradually and greatly increased. This increase lasted 50-90 hours after precipitation. (This process should last as long as there is water in the soil cover. I was able to measure it for 110 hours.)

The drip-measurements can be completed with the evaluation of crevice-statistics of the rock ***[Kovács and Balásházi 1975; Kovács 1979]***, so the infiltration equivalent value of karstic rocks could be approached from two directions. This method is beneficial for the determination of the characteristics of a greater area.

The characteristics of the infiltration into karstic rocks can be used for the delineation of the hydraulic of infiltration protective zone for environment protection purposes, for example Esztramos ***[Lénárt, 1986c, 1990, 1997a]***.

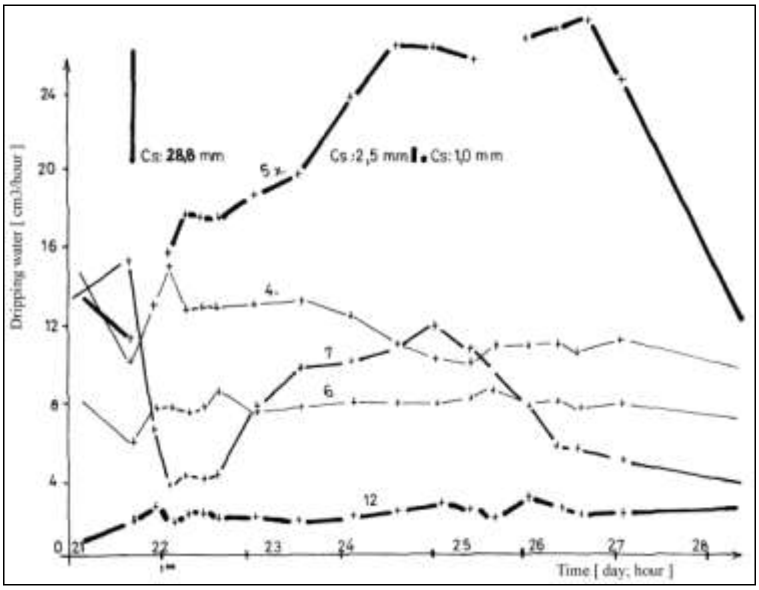


Fig. 3.3.11 Results of the dripping water measurement in the Létrási-Vizes cave, 20-27.08. 1973 [Original, 1973] (Legend: Cs: precipitation; 5x, 4, 7, 6, 12: number of measurement point, see Figure 2.2.2)

3.10. Karst water levels, changes in the amount of karst water

3.10.1. Changes in the karst water level

The situation of karst water–relief is very interesting both for the researchers, both for the water users. In many cases there is only lean amount of data for its preparations. In the simplest and least accurate case we have to compile the map based on the spring outings data.

The accuracy of the map to be compiled can be influenced greatly by large caves in the area, especially if those caves reach the karst water level. (There are about a dozen of such caves in the Bükk. When the karst water level reaches maximum, a lake forms in the cave, or the existing lake's water level greatly increases. Sometimes dry passages get under water for some time period.)

The most accurate maps can be devised by data from monitoring wells. ***Figure 2.2.1*** shows the locations of karst water monitoring in the Bükk. (There are over 30 karst water levels monitoring wells in the Bükk. In the Aggtelek Karst there are only a few ***(Figure 1.3.6)***. In the Slovak Karst, all the wells are situated in the valleys ***(Figure 1.3.5), [Havas et al., 2003]; (Figure 3.4.28), [Šalagová et al., 1997]; (Figure 3.4.29), [Tometz, 2000]; (Figure 3.4.30), [Lénárt and Tometz, 2004]***.)

There are many concepts regarding the karst water level ***[Pávai-Vajna, 1950; Szilágyi, (1969), 1975; 1980; Böcker, 1969; Tóth, 1976; Böcker and Dénes, 1977, 1978; Szilágyi at al., 1980; Böcker and Vecsernyés, 1983; Izápy and Maucha, 1992; Juhász and Lénárt, 1993; Havas et al., 1995]***. This last one seems to be the most useful to me, despite all of its inaccuracy, so I will accept this as starting data. (See ***Figure 3.4.22***.)

3.10.1.1. Results of measurements in the Bükk, in the monitoring wells

The most important water level monitoring well is the Nv-17 (= Nv-8). Let me present the entire collection of measurement data, including the supplements ***(Figure 3.4.1)***, the precipitation ***(Figure 3.4.2)***, and the results for the entire last year ***(Figure 3.4.3)***. No production well influences this well directly, which is the highest-situated monitoring well of the Bükk.

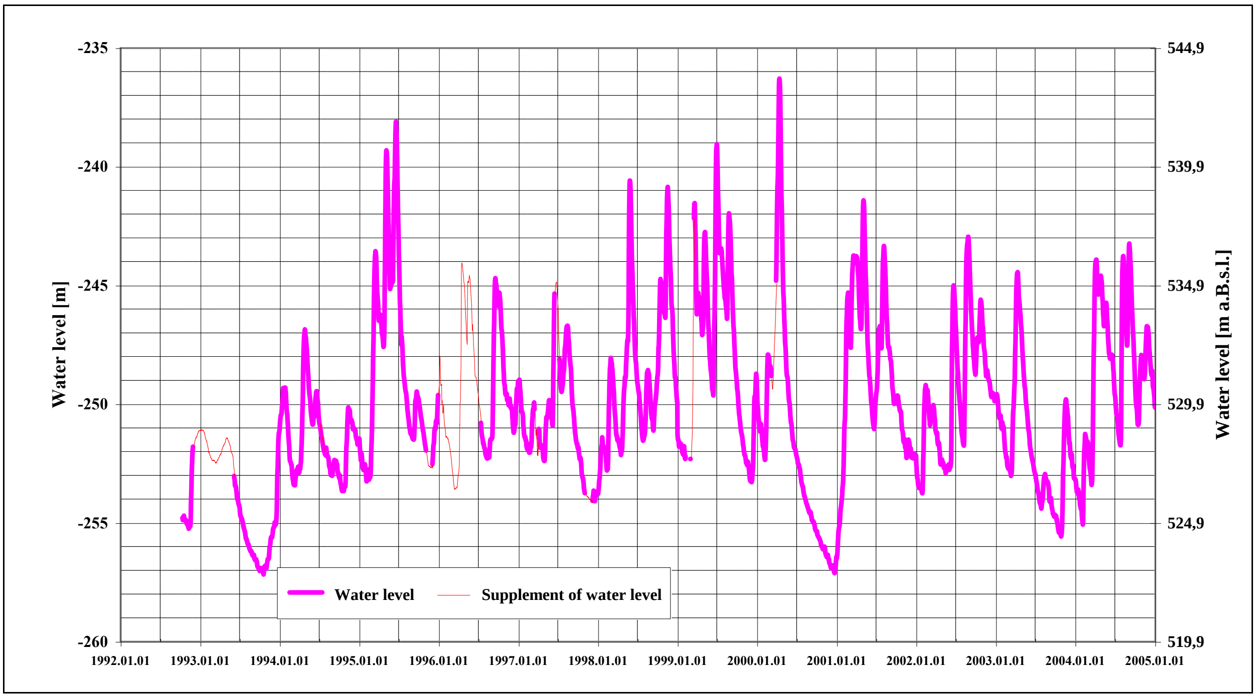


Fig. 3.4.1 Karst water level in Nv-17 (=Nv-8) monitoring well, 1992-2004. [Original, 2005]

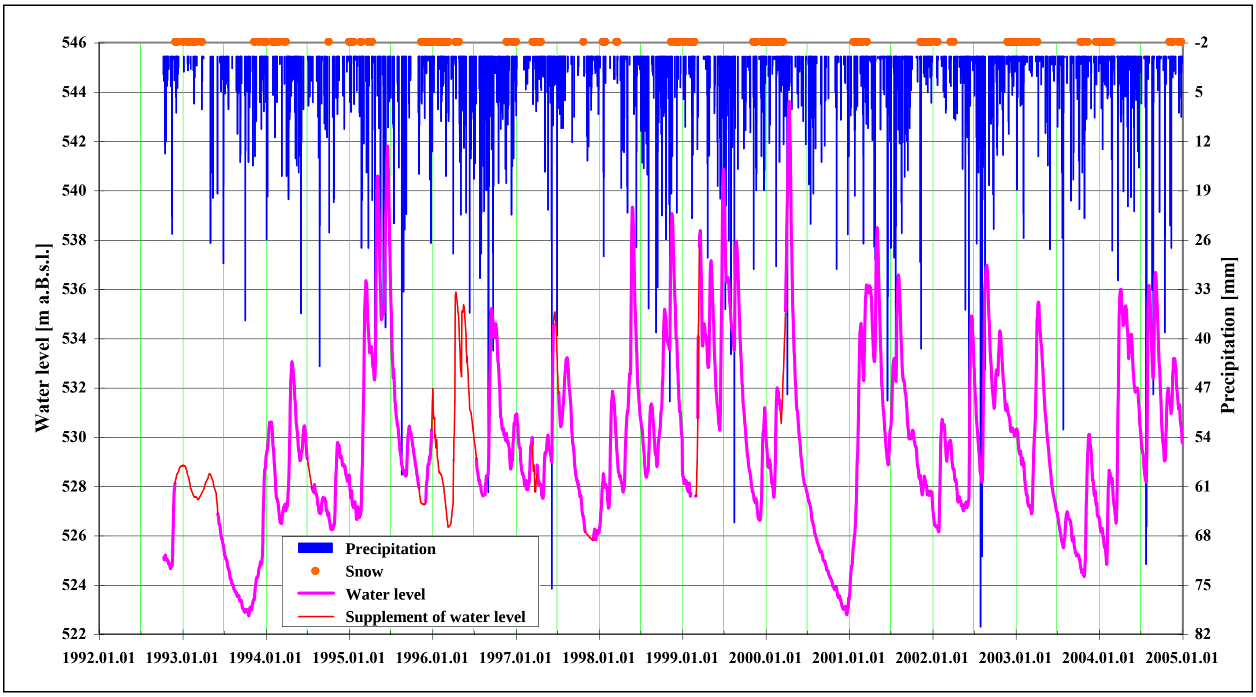


Fig. 3.4.2 Karst water level in Nv-17 (=Nv-8) monitoring well, 1992-2004 [Original, 2005]

The other important monitoring well on the plateau is the Répáshuta Tbp-1. Its data shown on ***(Figure 3.4.4)***. There is no direct influence of production well to this well either.

This is situated much lower than the one we previously talked about, and it is right in front of a water movement blocking shale zone.

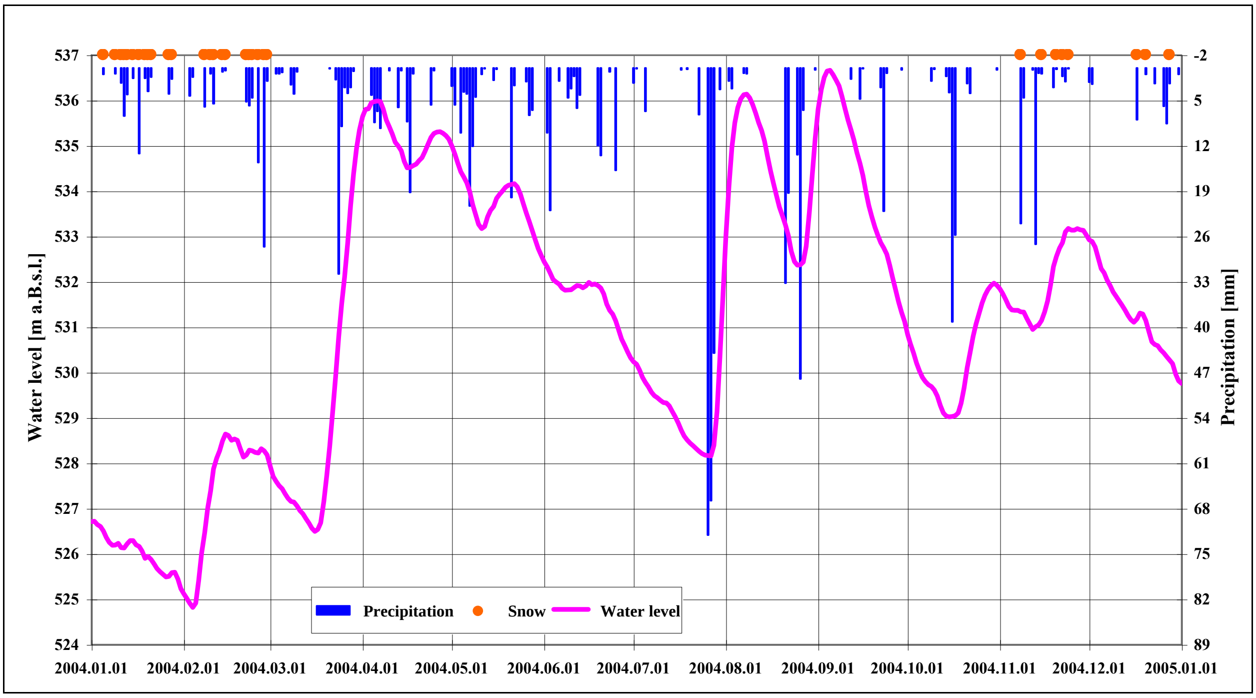


Fig. 3.4.3 Karst water level in Nv-17 (=Nv-8) monitoring well, 2004 [Original, 2005]

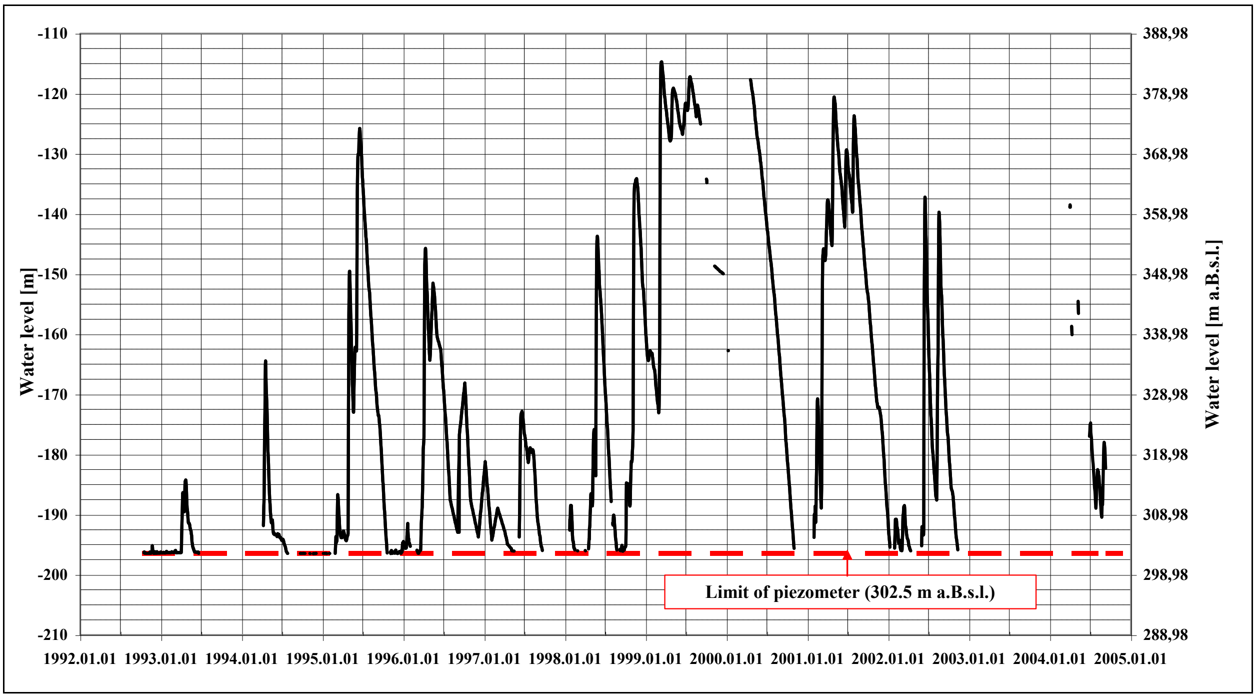


Fig. 3.4.4 Karst water level in Répáshuta (Tebepuszta), Tbp-1 (Rh-1) monitoring well, 1992-2004 [Original, 2005]

The third significant monitoring well is in the Southern Bükk, near Felsőtárkány, in the Lök valley. Its changes can be seen on ***(Figure 3.4.5)***. This well is probably free of the influence of any production well, too. It produces very high water level fluctuation, even though it is situated in a valley.

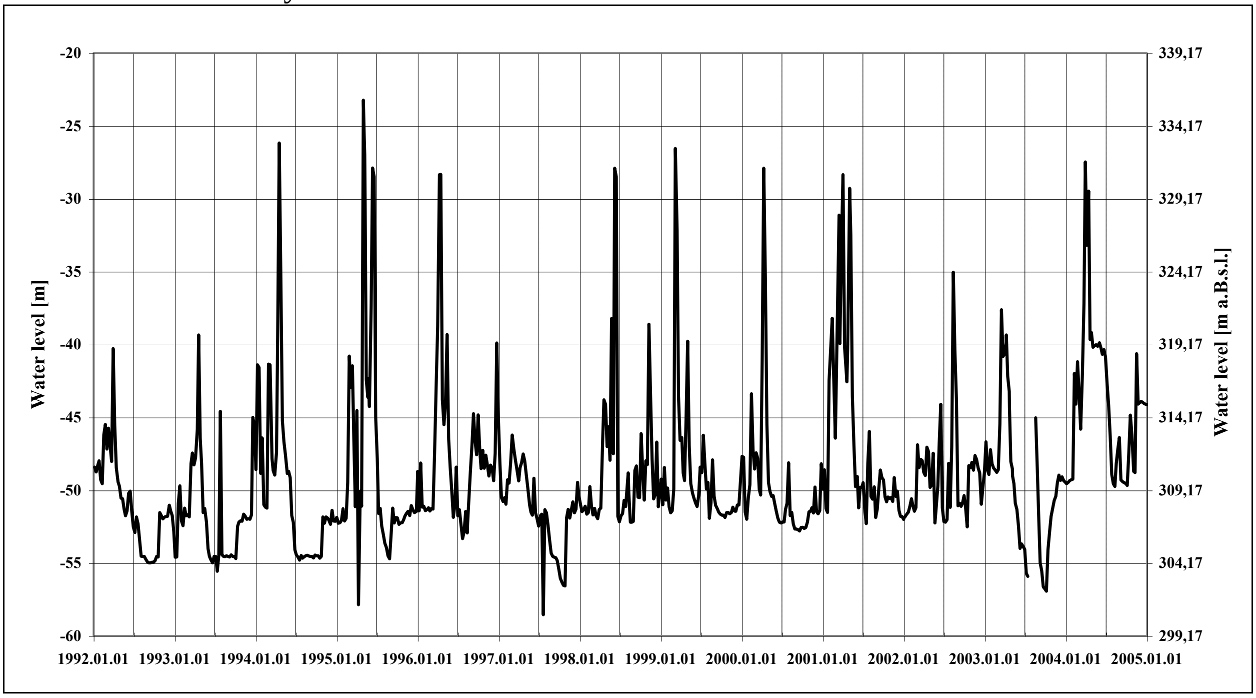


Fig. 3.4.5 Karst water level in Felsőtárkány (valley Lök), L-1 monitoring well, 1992-2004 [Original, 2005]

The fourth significant monitoring well is also in the Southern Bükk. It is near Felsőtárkány, called Sz-5 monitoring well ***(Figure 3.4.6)***. Nearby, a little bit upward, there are the pumping wells of Barátrét, which obviously effect the monitoring well. The Barátrét wells are supplying water for Felsőtárkány, and these wells mean a potential water reserve for Eger.

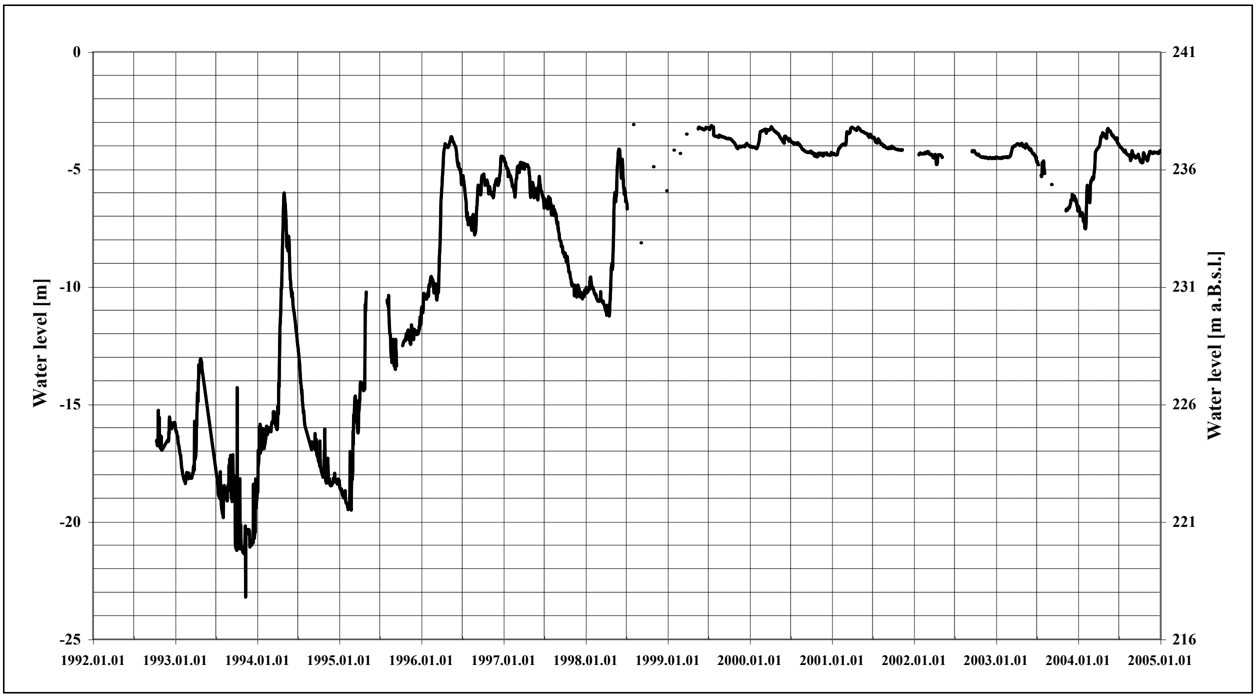


Fig. 3.4.6 Karst water level in Felsőtárkány, „Sz-5" monitoring well, 1992-2004 [Original, 2005]

The fifth significant well is near the Southern Bükk, in covered karst area. This is close to Mezőkövesd. The well is the No.3 monitoring well of the Zsóry Bath ***(Figure 3.4.7)***. The effects of the nearby production wells are certain. (The well is situated beneath 900 m non-karstic rock.)

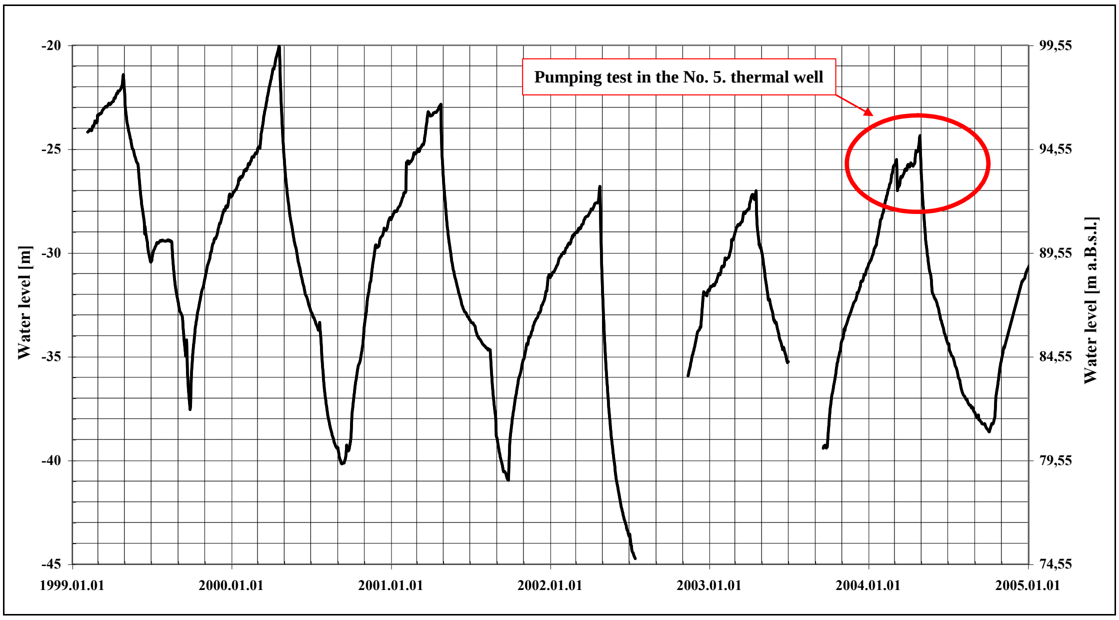


Fig. 3.4.7 Karst water level in Mezőkövesd, Zsóry bath No. 3. (monitoring) well, 1999-2004 [Original, 2005]

There are regular water level measurements happening in the P-1 production well of Eger ***(Figures 3.4.9-3.4.10)*** when the pump is shut off. Obviously the nearby production wells and springs affect this well. The P-1 is situated on the covered karst, beneath a few meters of sediment layer. It is one of the most significant water sources in the Eger area.

Fig. 3.4.8 Karst water level in Eger, Petőfi square, No. 1. well, 1993-2004 [Original, 2005]

Water level measurements in the Szinva spring ***(Figure 3.4.9, 3.4.12)***. The water is being exploited from the spring through gravity. This is one of the most significant springs in the part of the Bükk which is closest to Miskolc. (Let me present the data from year 2004 as well in order to show more detailed picture of the characteristics of the water level fluctuation ***(Figure 3.4.10)***. The threshold level of flood overflow is 344,33 m a.B.s.l. = -1,87 m)

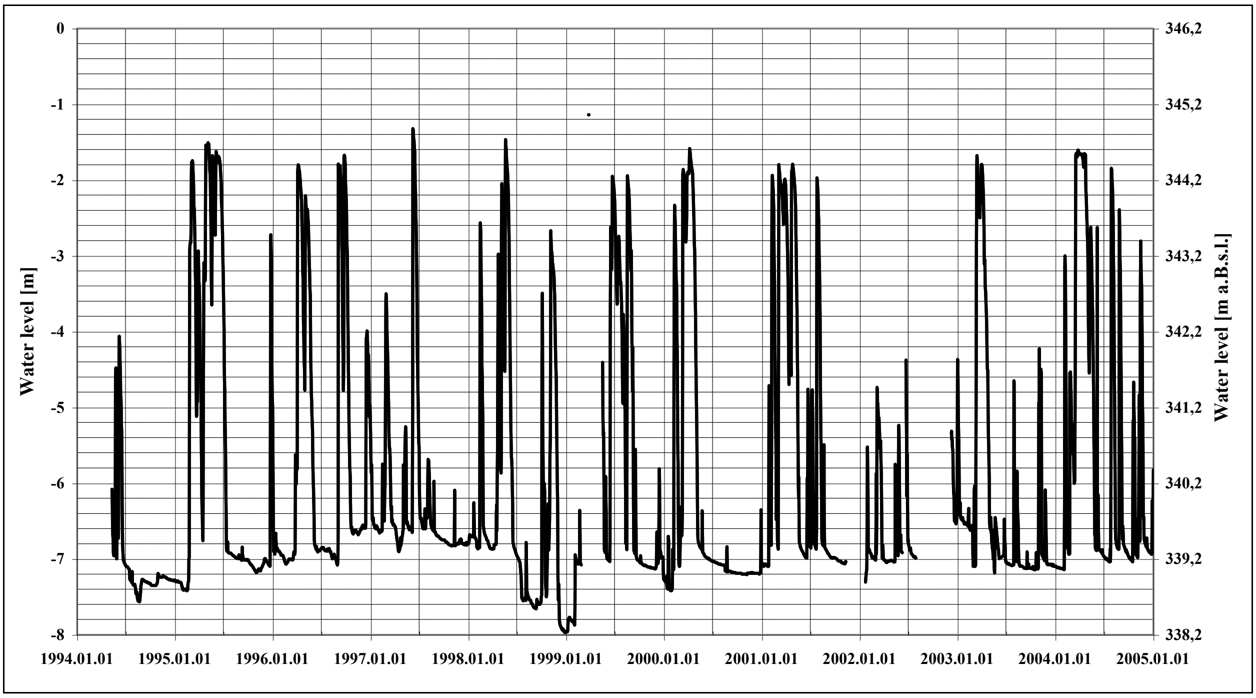


Fig. 3.4.9 Karst water level in Miskolc, Szinva spring, 1994-2004 [Original, 2005]

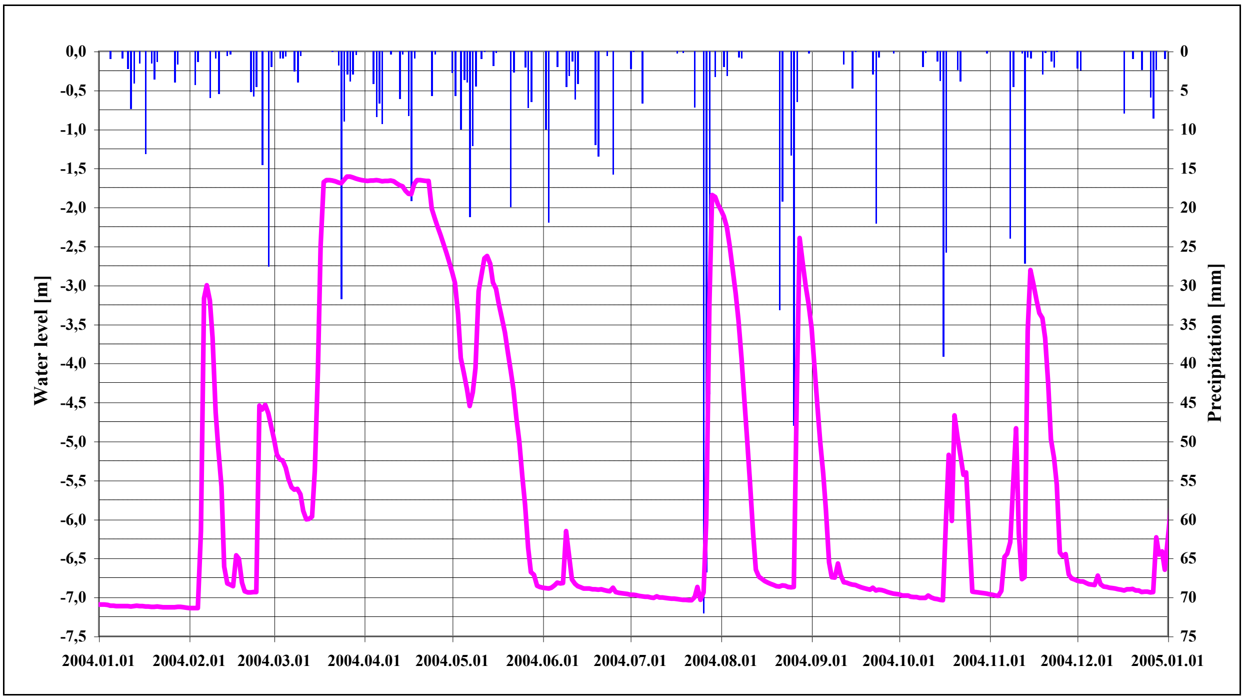


Fig. 3.4.10 Karst water level in Miskolc, Szinva spring, 2004 [Original, 2005]

The results of water level measurements in the Garadna spring is shoun on ***Figure 3.4.11***. The water is being exploited from the spring through gravity, but the amount of water is not significant. (This means that the ecological water resources are vast in the area.) ***Figures 3.4.12-3.4.14*** shows a water temperature diagram and a water level measurement chart, both for the Szinva and Garadna springs and for the same period of time, in order to illustrate the similarities between the activities of these two springs.

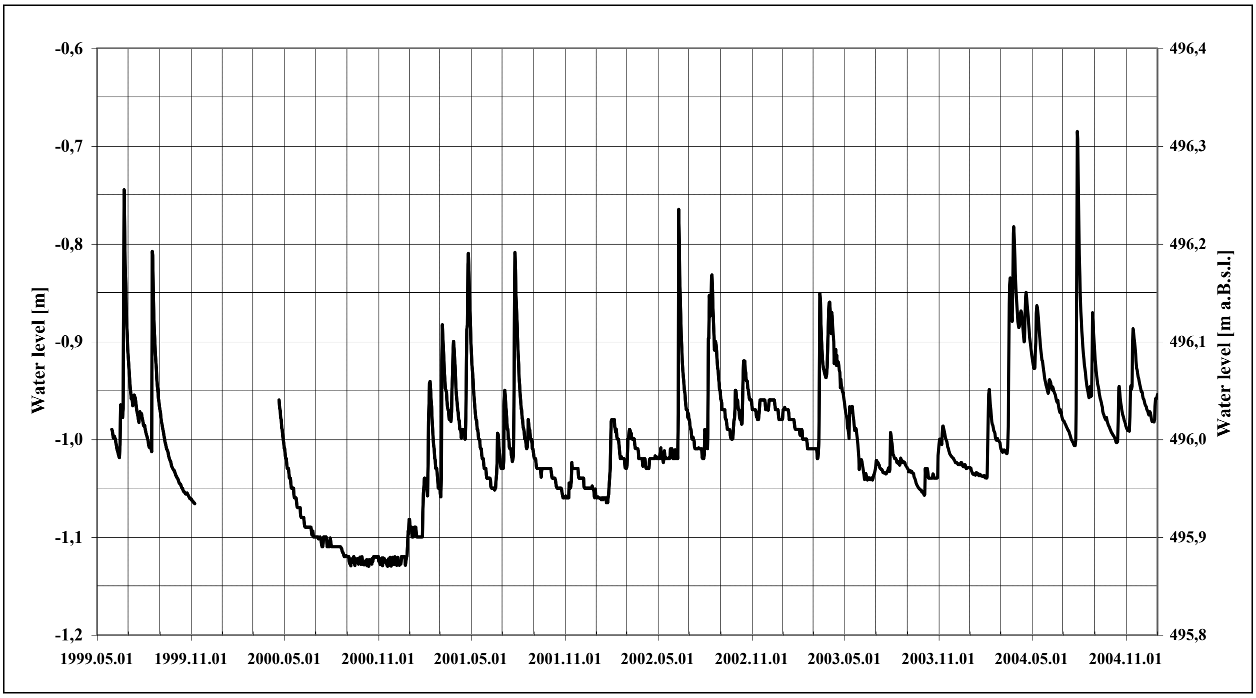


Fig. 3.4.11 Karst water level in Miskolc, Garadna spring, 1999-2004 [Original, 2005]

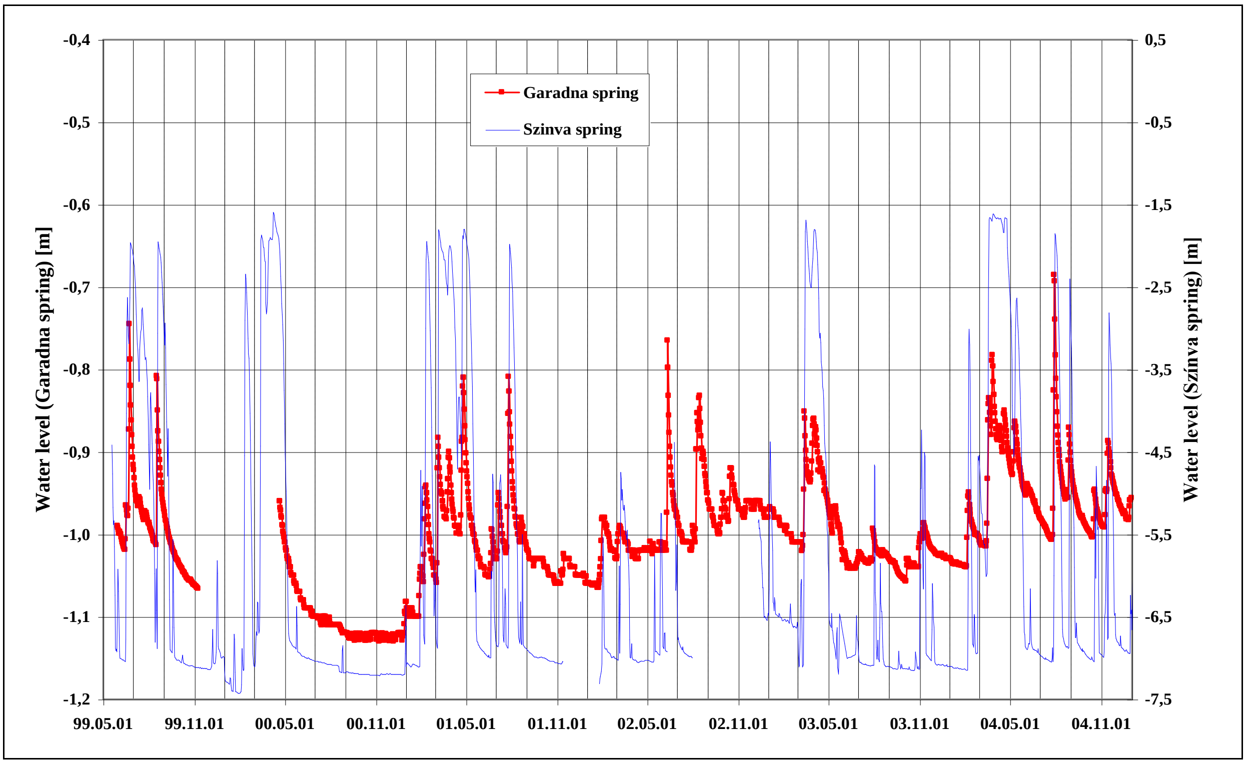


Fig. 3.4.12 Karst water level in Miskolc, "Garadna" spring and "Szinva" spring, 1999-2004 [Original, 2005]

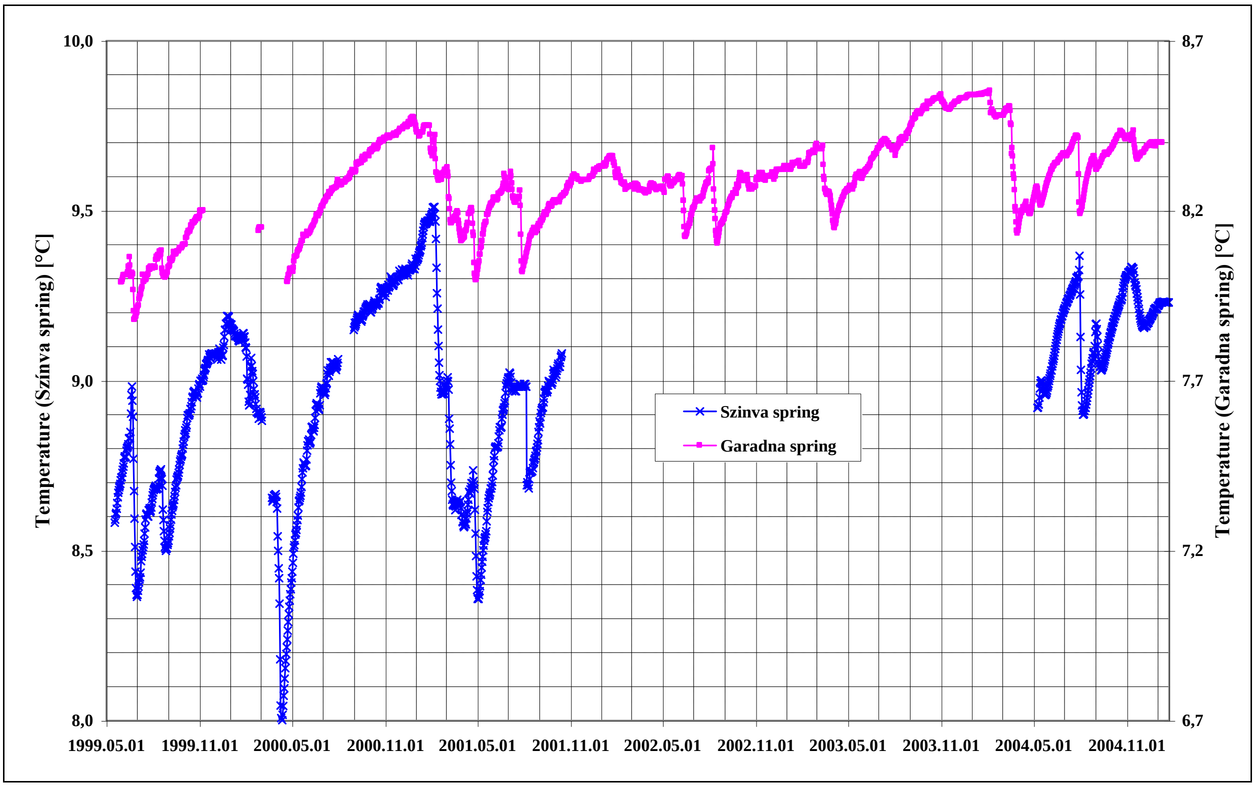


Fig. 3.4.13 Karst water temperature in Miskolc, "Garadna" spring and "Szinva" spring, 1999-2004 [Original, 2005]

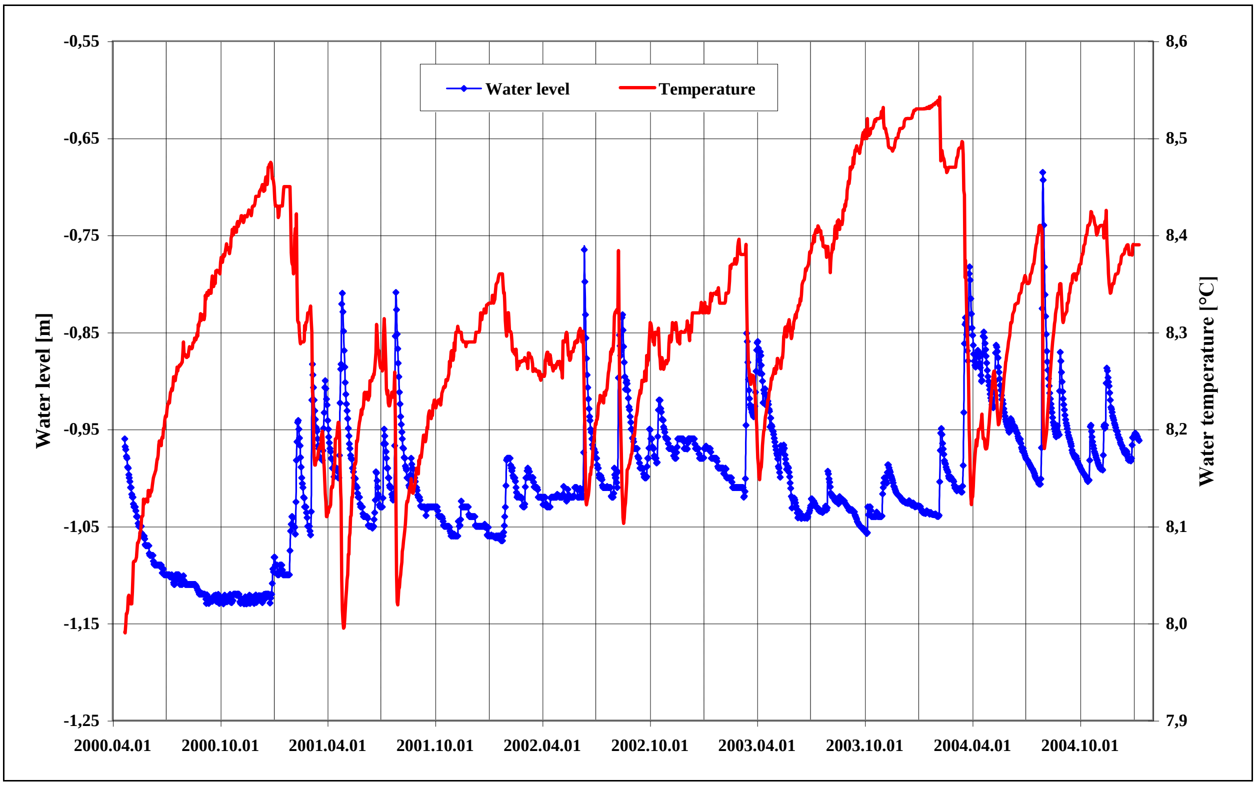


Fig. 3.4.14 Karst water level and temperature in Miskolc, "Garadna" spring, 2000-2004 [Original, 2005]

The edges of the above mentioned monitoring wells of the Bükk Mountains (wells and springs) are between 127-734 m a.B.s.l. (There is a thermal water well in the Bükk surroundings we will talk about later that was once a thermal well turned into a monitoring well. We will not discuss its water level data here.) Among the maximum water levels the lowest was at 127 m a.B.s.l. (Miskolctapolca, overflow of Új-kút, edge of mountain), the highest was at 544 m a.B.s.l. (Bükk, Nagyfennsík, Nv-17). The minimum was at 113 m a.B.s.l. (Miskolctapolca), the highest level of the minimum was at 523 m a.B.s.l., Nv-17. (These values mean 410-415 m water level changes – more than 40 bar (4 MPa) – in the Bükk Mountains, and this is very important in terms of thermal water formation.) Finally there are the springs at the edge of the mountains that has a water level change within 1 m, (Mónosbél, Kács, Sály), but the greatest water level fluctuation is in the Tbp-1 well, more than 83 m! (The exact value cannot be determined because the well sometimes dries out. In the nearby Pénz-swallowhole fluctuations of cave water level over 90 m were noted in the seventies and the eighties.)

There are at least 5 years worth of data in the Bükk from the following monitoring system: 6 drilled monitoring borehole, 2 unused wells turned into monitoring wells, 1 producing well, and 7 caption of a spring. Out of the seven 5 is shafted, one is tunneled and one is lofted. There is no room for the detailed analysis of all these, so I will shortly introduce the most important one, the Nv-17 well's characteristics. The water level averages in this well between ***01.11.1992 – 01.11.2004 (Table 3.4.I)***:

Table 3.4.I

Maximum average	**538.81 m a.B.s.l. (monthly)**	**543.60 m a.B.s.l. (daily)**

Average	**530.13 m a.B.s.l. (monthly)**	**529.73 m a.B.s.l. (daily)**
Minimum average	**523.18 m a.B.s.l. (monthly)**	**522.73 m a.B.s.l. (daily)**
Difference	**15.63 m (monthly)**	**20.88 m (daily)**
Max/Min	**1.030 (monthly)**	**1.0399 (daily)**

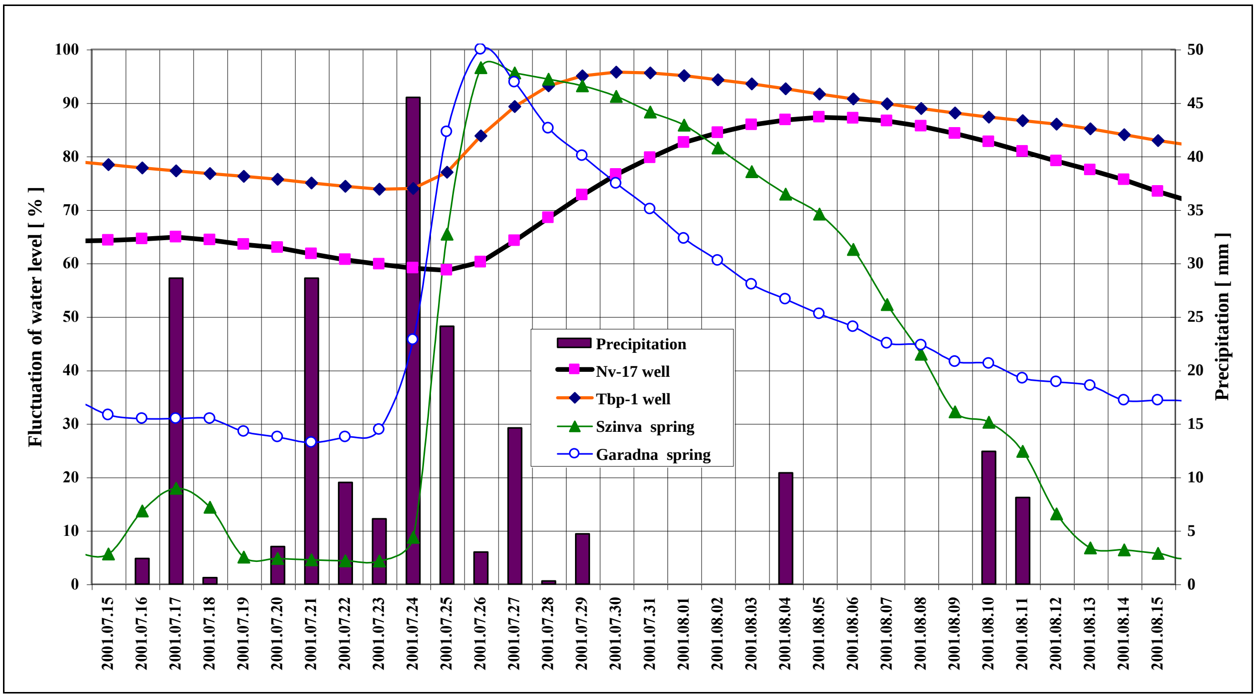


Fig. 3.4.15 Water level fluctuations due to precipitation in July-August, 2001 [Original, 2005] (Legend: % = [(daily value – minimum value) / (maximum value – minimum value)]*100; at measuring points)

The highest part of the karst water relief of the Bükk is at 523-544 m a.B.s.l., the lowest value of the karst water level at the most important drainage and lowest area of the Bükk (Miskolctapolca) is at 113-127 m a.B.s.l. This pressure difference of over 40 bar (4 MPa) is „controlling" the changes in karst water level in the Bükk. There is no agreement among professionals about the solid karst water level in the Bükk. In my opinion the karst water level of Bükk is interconnected, but the aquifers of individual springs are not unifically connected to each other. The depth of the evaluation decides in any given area that to what extent individual aquifers can be separated. Otherwise the scale of the map decides if a unified water relief can be shown, or serious „jumps" can be noted in the water levels at the connecting rim of the part-aquifers.

The different measurement sites react to the precipitation from „bottom to top" ***(Figure 3.4.15)***. The sequence is Szinva→Garadna→Tbp→Nv17. These are different from each other in time, but unified for the entire mountains. So the spreading of the pressure is getting through the fault system of impermeable layers. Conclusion: the Bükk is a unified cold karst water system. (Must be noted that the most dynamic changes are taking place at the springs close to the edge of the mountain – Szinva, Garadna.)

3.10.1.2. Exploitation from Bükk Mountains

The fluctuation of water levels in the wells and springs of the Bükk can be only understood and discussed if we are familiar with the karst water production and exploitation of the Bükk. The total exploitation is shown on ***Figure 3.4.16***.

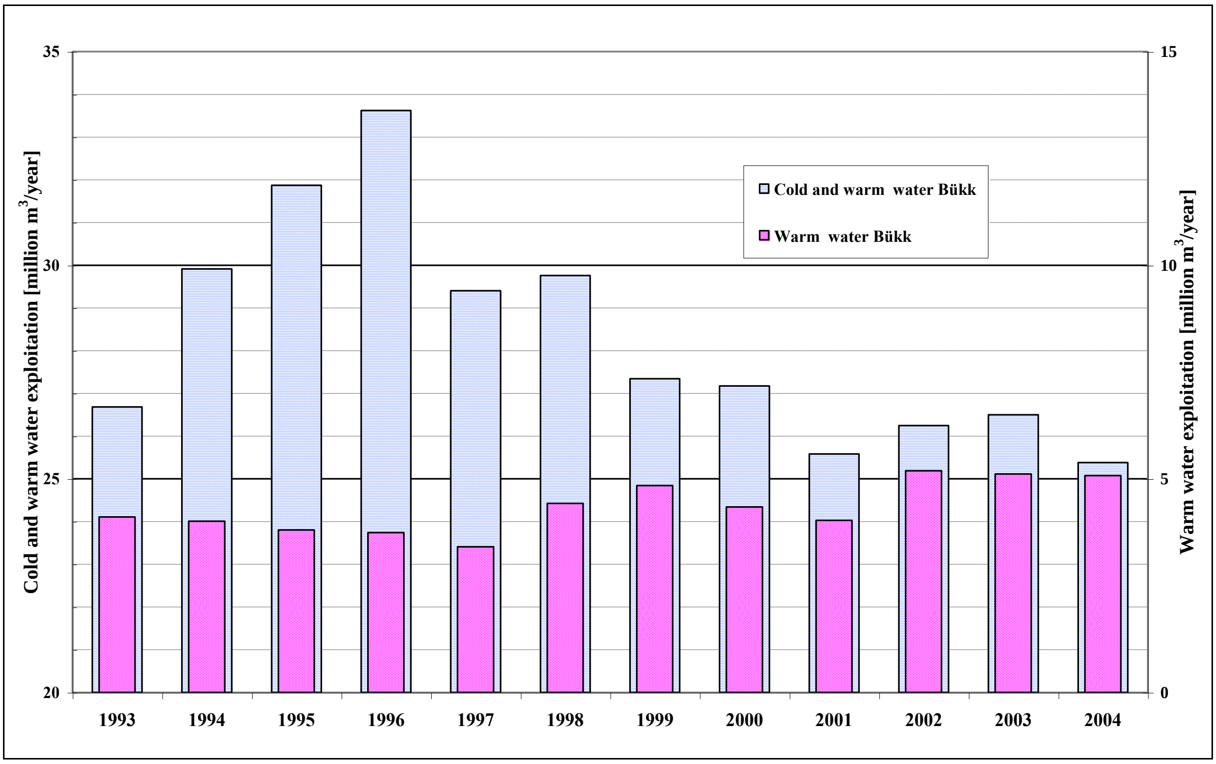


Fig. 3.4.16 Karst water exploitation from Bükk Mountains [Original, 2005]

Three large and many small water users are involved in the total karst water exploitation of the Bükk. (The summarized production of the small ones doesn't reach the production of even the smallest of the big ones. It must be noted, though, that there must be a water amount of about 10 % which is not shown in our results, due to technical difficulties of the measurement method.) ***Figure 3.4.17*** shows the annual production broken up by different producers.

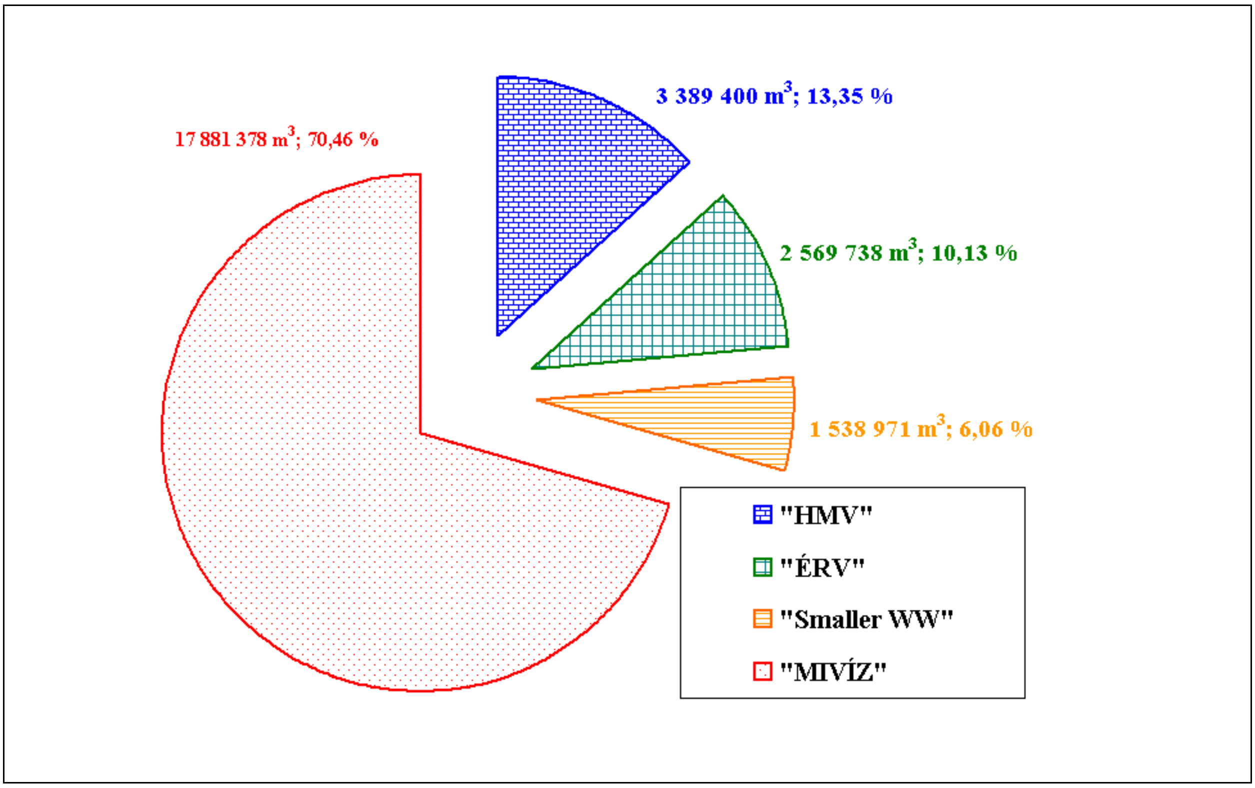


Fig. 3.4.17 Karst water exploitation from Bükk Mountains at 2004 (See chapter 2.2.2) [Original, 2005]

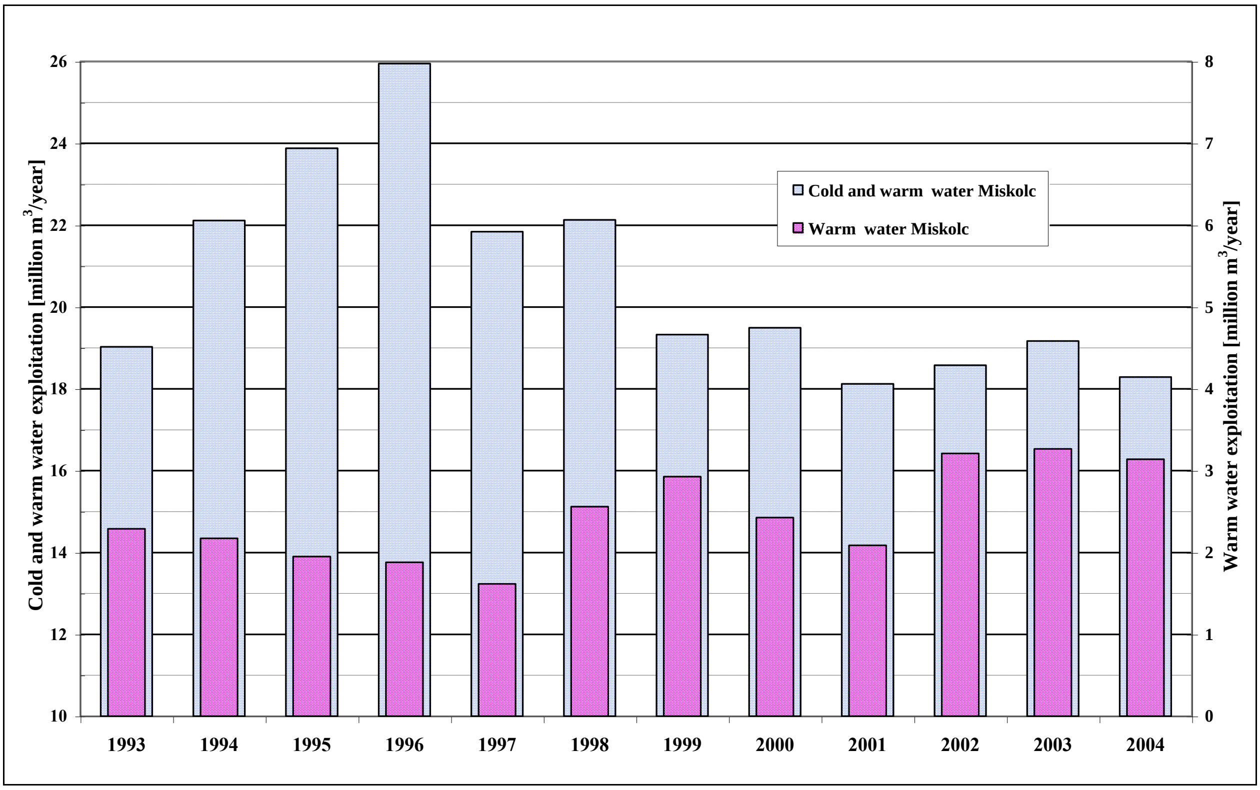


Fig. 3.4.18 Karst water exploitation from Bükk Mountains in Miskolc [Original, 2005]

The biggest amount of water is being exploited from the Bükk by the largest settlement of the area, Miskolc ***(Figure 3.4.18)***. A few characteristics:

- App. 73 % of the karst water exploitation of the Bükk happens at Miskolc
- App. 15 % of the karst water exploitation of the Bükk is warm or warm-tepid karst water. (The above mentioned water amount which cannot be taken into account is warm and tepid-warm karst water, mostly used for bathing purposes).
- 55 % of the thermal karst water exploitation of the Bükk takes place at Miskolc. (The amount of warm and tepid-warm karst water that cannot be taken into account doesn't surfaces at Miskolc, but at Eger).
- The thermal karst water exploitation of Miskolc is 12 % of the total karst water exploitation

The expansion of the Bükk is about 450 km^2. Out of this area 207 km^2 is open karst. There is a 25 km^2 non-karstic area that passes its water directly to the karstic area. The exploitation of the karst water of the Bükk presently amounts to about 60 to 70 % of the total dynamic water resource, which is still within the quantity of water allowed for this purpose. (In the 1990's the exploitation was close to 90 %. Certain authors, like ***Izápy and Sárváry, [1992]*** thought that it actually exceeded the 100 %, meaning that an overexploitation happened. According to my evaluation, the annual dynamic water resources are about 53.000.000 m^3 at present. (***Pados, [2003]*** thinks it is 55.000.000 m^3.)

The Slovak Karst is 389 km^2 ***[Kullman, 1990]***, according to prognosis its groundwater resources is about 107.000.000 m^3 per year. ***Havas et al., [2003]*** thought that the quantity of exploitable karst water in the Mesozoic rocks is about 41.000.000 m^3 annual; out of which the amount of about 2.000.000 m^3 is being actually exploited. (It amounts to 5 % of the total dynamic karst water reserve.) Most of the water exploited for satisfying consumer demands comes from the sediments.

The Aggtelek Karst spreads to 202 km^2. Out of this 114 km^2 is triad limestone and dolomite plateau, 88 km^2 impermeable rock. Its dynamic karst water resources are about 18.000.000 m^3, out of this 125.000 m^3 is being exploited annual. (It is about 1 % of the total dynamic karst water resources.) The allowed possible exploitation is 315.000 m^3 per year. The karst water resources of the Szendrő Mounts are an additional 12.000.000 m^3 per year ***[Pados, 2003]***.

The monthly averages give better chances for more accurate analysis besides the annual exploitation averages and summaries. ***Figure 3.4.19*** shows all of the monthly averages but only the data of some of the more significant years had been connected by a continuous line. These significant values are the highest exploitation year (1996) and the lowest one (2004). Besides these, I marked the average, and the year 2000 data with dotted line, for its extreme precipitation results.

Figure 3.4.20 clearly shows that the karst water level has a spring and summer maximum. The production has a summer maximum. Even though these are not present at the same time, still, there is no overexploitation in the Bükk with the present production values. (Unfortunately, the evaluation of the ecological water resources is still not done. Despite this, in my opinion the karst water production have not harmed the ecological water resources of the Bükk. As we have seen previously, the karst water production is very small compared to the amount of exploitable water resources in the Slovak Karst and Aggtelek Karst.)

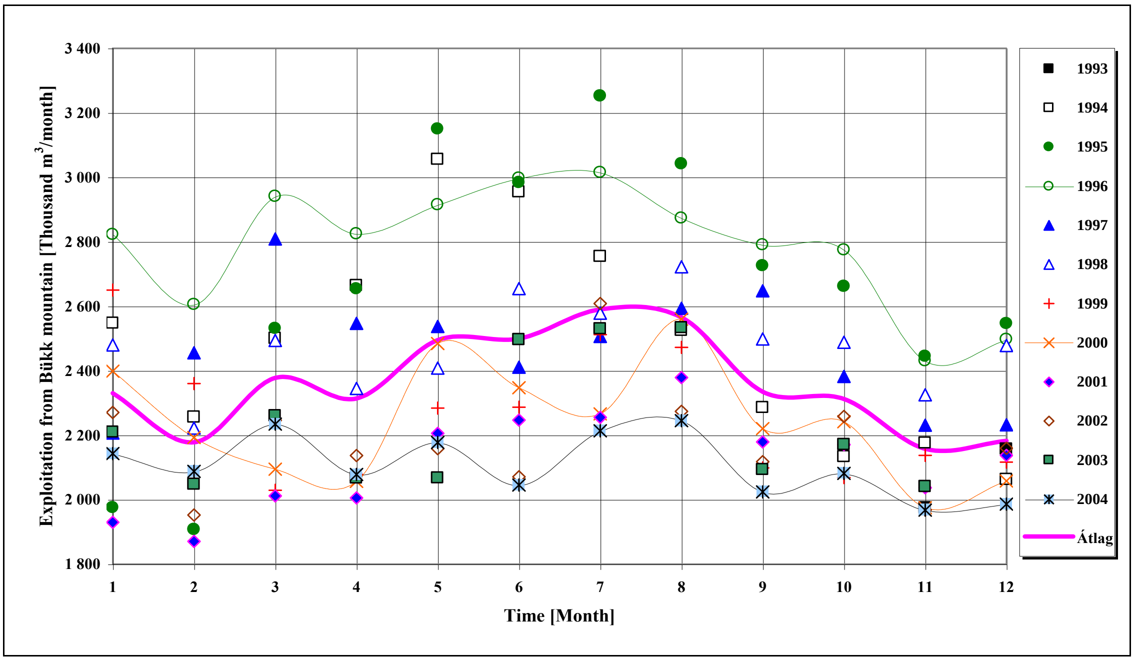


Fig. 3.4.19 Karst water exploitation from Bükk Mountains by month [Original, 2005]

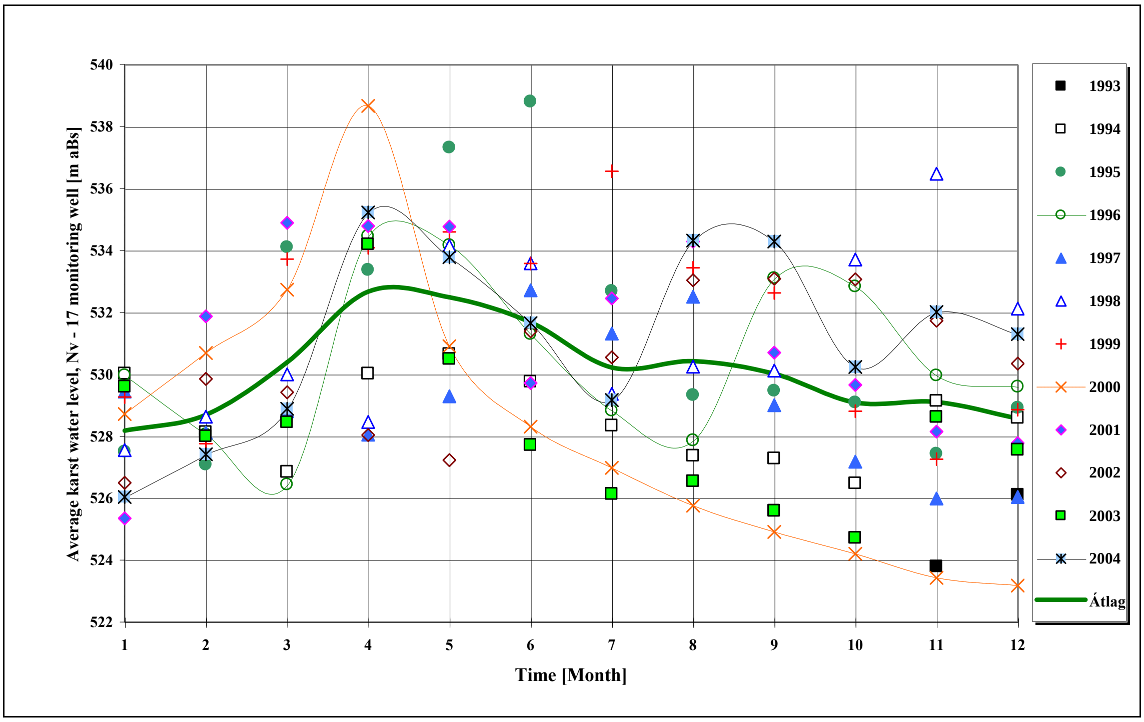


Fig. 3.4.20 Karst water level in Bükk Mountains broken up by month [Original, 2005]

3.10.1.3. Water level changes in the mine of Recsk

The creation of the planned ore mine at Recsk had started at 1961, with continual de-watering. About 800 000 m^3 of karst water had been lifted out yearly, which contained high amount of salt. (Due to financial reasons, the planned ore mine had never become a productive establishment.)

The dewatering of the Recsk ore mine has leased on November14th, 1999, so the mine shafts and tunnels became flooded. According to the prognosis, the water level in the mining shafted area will become the same as the starting, natural level around 2030-2050. The evaluations are proving necessity of a longer fill up time period, and for first glance it can be well-related to the water level changes of the Bükk ***[Geokom, 2000; Somody and Lénárt, 2002, 2004] (Figures 3.4.21-3.4.23)***.

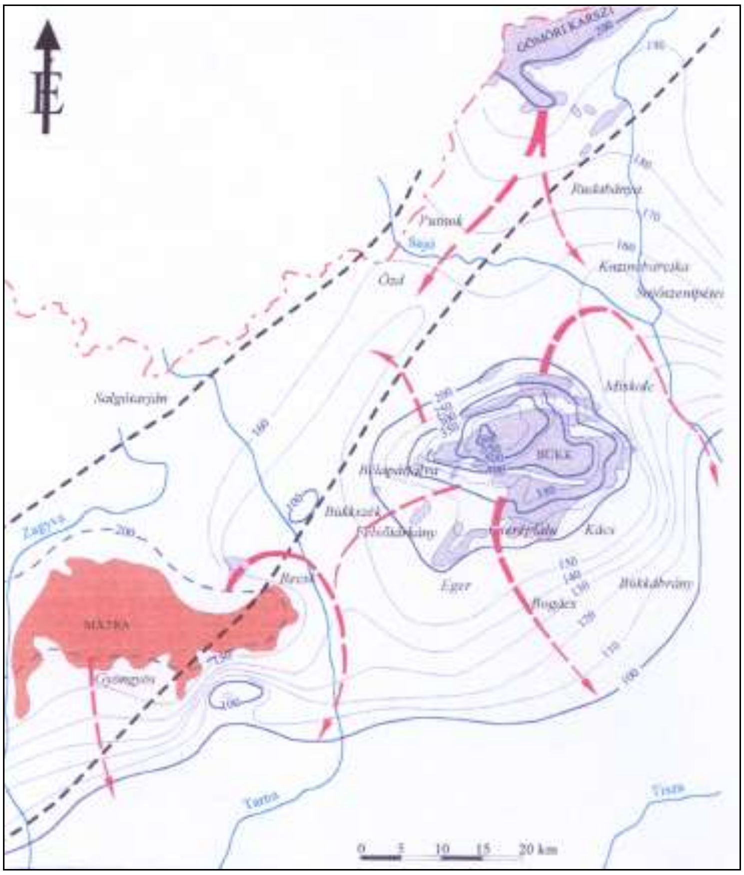


Fig. 3.4.21 Hydrodynamic sketch in Gemer-Bükk area at 1977 [Geokom, 2000]

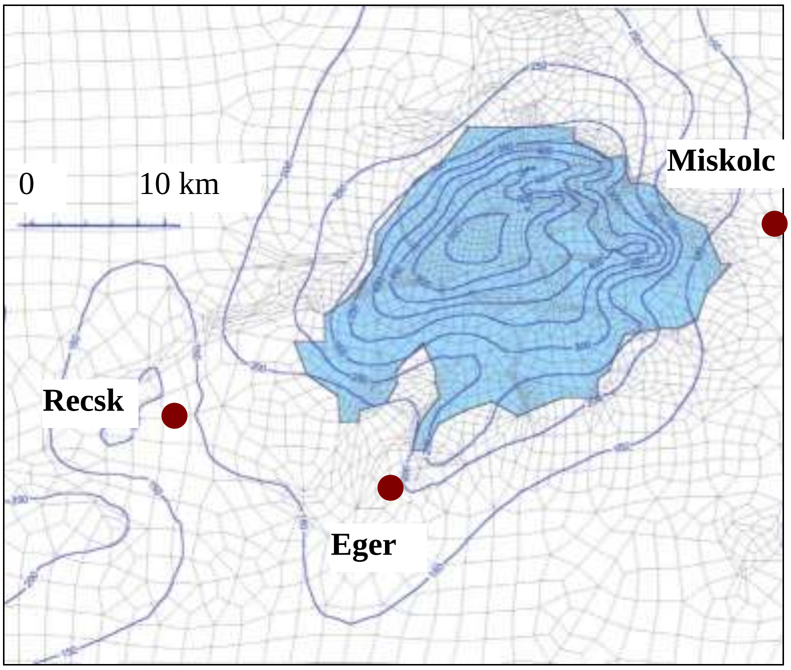


Fig. 3.4.22 Map of calculated karst water level in Bükk and Mátra area at 1995 [Mező, in Havas, 1995]

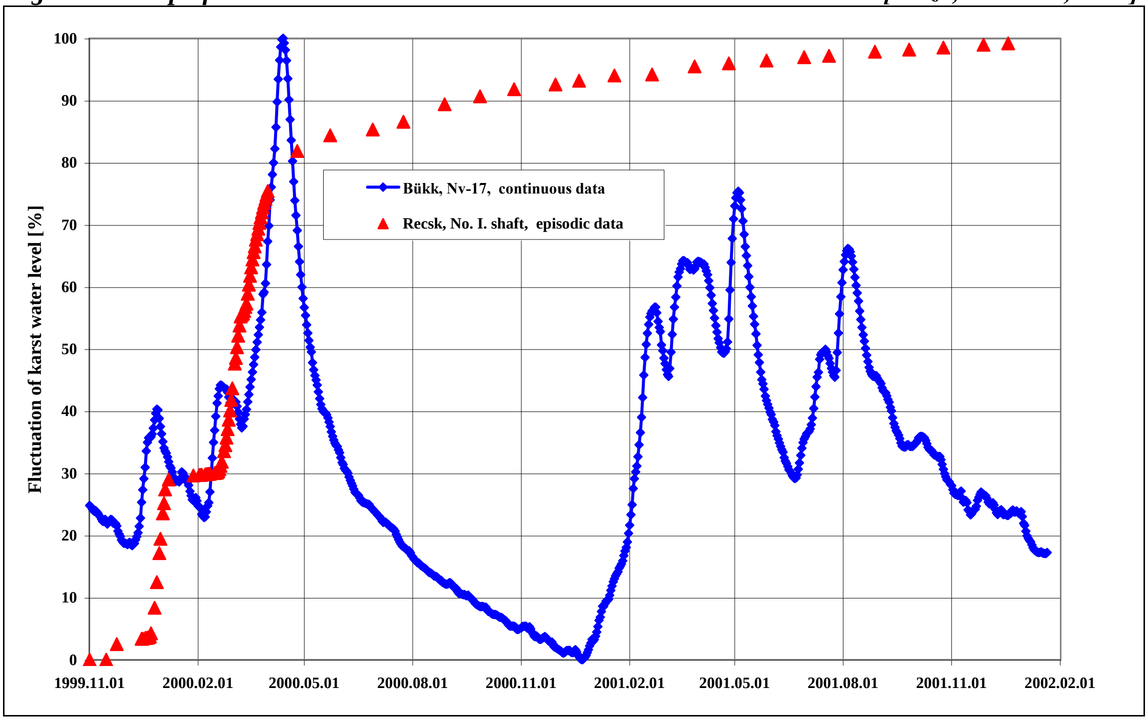


*Fig. 3.4.23 Karst water level in the Bükk Mountains and Recsk [Somody and Lénárt, 2002, 2004] (Legend: % = [(daily value – minimum value) / (maximum value – minimum value)]*100; at measurement points)*

In the first phase of our assessment we had the impression that further research is more than necessary since the connection is very clear. The filling up of the mining shafts and tunnels - with different airspace and at different levels under the surface - can be drawn up in diagrams that show the pressure changes due to the karst water level of Bükk. (These changes mostly can be followed by the changes in the steepness of the diagrams.)

One of the tasks of the monitoring system is to help clear up the regional conditions. The BKMI ***[Havas et al., 1995]*** devised a geographical map, a karst water level map, and a conductivity map of the Bükk Mountains in 1995. The east side of every single one of these maps showed Recsk and its surroundings very strongly. The maximum of the karst water relief can be found in the Nagyfennsík, in the Bükk, with the value of approximately 550 m a.B.s.l., the most important depression area had been formed at the Recsk area. (The original water level approximately 100 m a.B.s.l..) These characteristics together with the maps published before and after, and the dripstones and their forms, their chemical composition had drawn our attentions that the fill-up process of Recsk should be dealt with within the frame of the Bükk karst water system.

3.10.2. The Bükk karst water level changes by daily averages

The assessed volumetric water resource of the Bükk is approximately 526.000.000 m^3. This amount represents the karst water in the limestone block that is situated between the lowest natural discharge level (127 m a.B.s.l., Miskolctapolca) and the minimum of the karst water level of Nagyfennsík (523 m a.B.s.l., Nv-17) The surface of the rock holding the karst water resource is 207 km^2, the value of the porosity is 0,75 %. (As in Chapter 3.4.1.2, was stated the dynamic karst water resources is 53.000.000 m^3, which amounts up to approximately 10 % of the volumetric karst water reserves. The dynamic karst water resources is cold, the volumetric resources is partly warm or warm-tepid water.)

I provided the starting data regarding the Bükk dynamic water system in chapter 3.2. The starting „0" is the value of the Nv-17 water level monitoring well at 11. 01. 1993, at the „drought of the century" (-256.92 m under field level, 522.98 m a.B.s.l.). During my assessment I

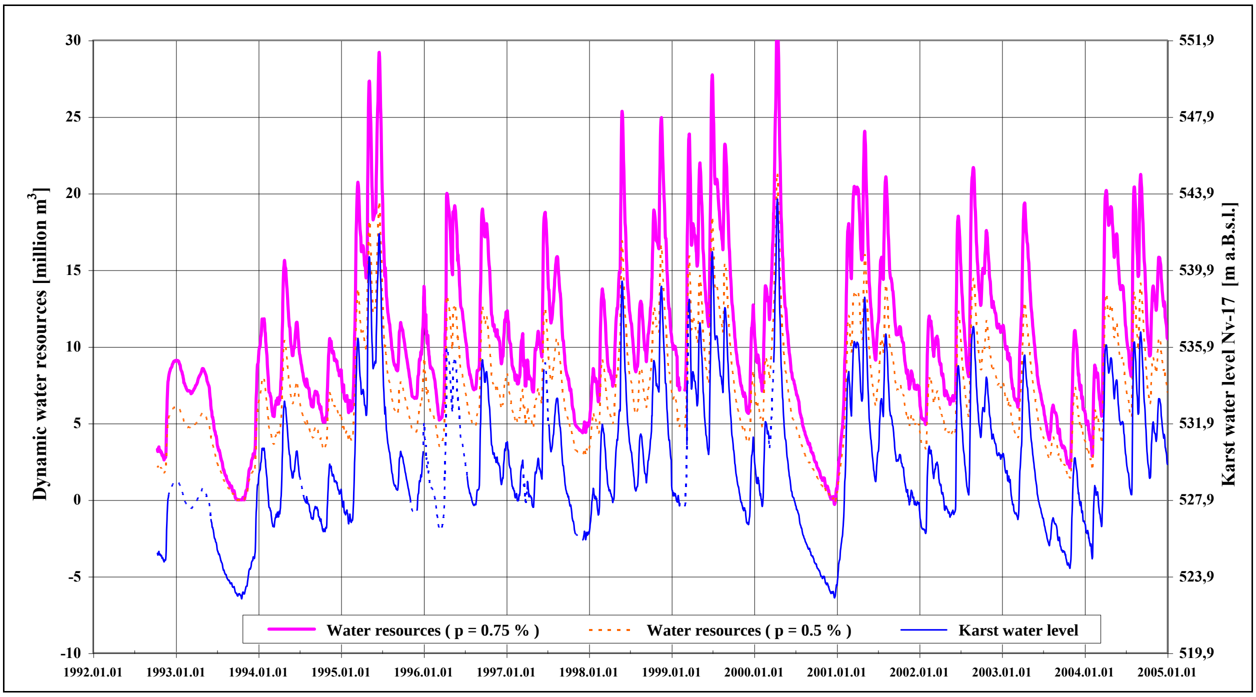


Fig. 3.4.24 The dynamic water resources of the Bükk by the water level of the Nv-17 karst water monitoring well [Original, 2005]

compared the momentarily, daily dynamic water resources to this value (among the experts there is no widely accepted value regarding this amount, so I determined it with 0,5 and 0,75

% gravitational porosity). ***Figure 3.4.24*** shows the results of my assessment. I marked the data supplement on the water level diagram, which data originated from other wells of the monitoring system.

One of the results of the Bükk Karst Water Level Monitoring is that I can provide monthly information to water exploiters regarding the available water resources based on the interpretation of my measurements. (The prognosis shall be discussed later.)

I publish the results of this continuously developing monitoring system toward the colleagues and other professionals through papers and conferences ***[Lénárt and Orbán, 1993; Lénárt et al., 1995a,b, 1996, 1997, 2002; Lénárt, 1997b,c, 2000, 2001, 2002, 2004a, 2005a,b]***.

3.10.3. The dynamics of karst water level changes

3.10.3.1. Elevation in the karst water level

Figure 3.4.25 shows the water level raise that exceeds 2 m, due to precipitation. (This is about 10 % of the maximum water level fluctuation.) Three very well separated phase can be examined, which is closely linked to the height of the karst water level:

- A daily increase of maximum 10 cm. This is a slow, starting phase, mostly applies to lower water levels. It can last for over a month, especially in the spring season.
- A daily increase of maximum 1 m elevation. It is a fast raising phase, mostly applies to medium water levels. It might last for the maximum of 2 weeks.
- A daily increase of a few centimeters, maximum 15 cm. It is a quickly slowing raise, a closing phase, which applies mostly to medium or high water levels. It lasts for maximum a week of time, and it changes into decreasing phase after.

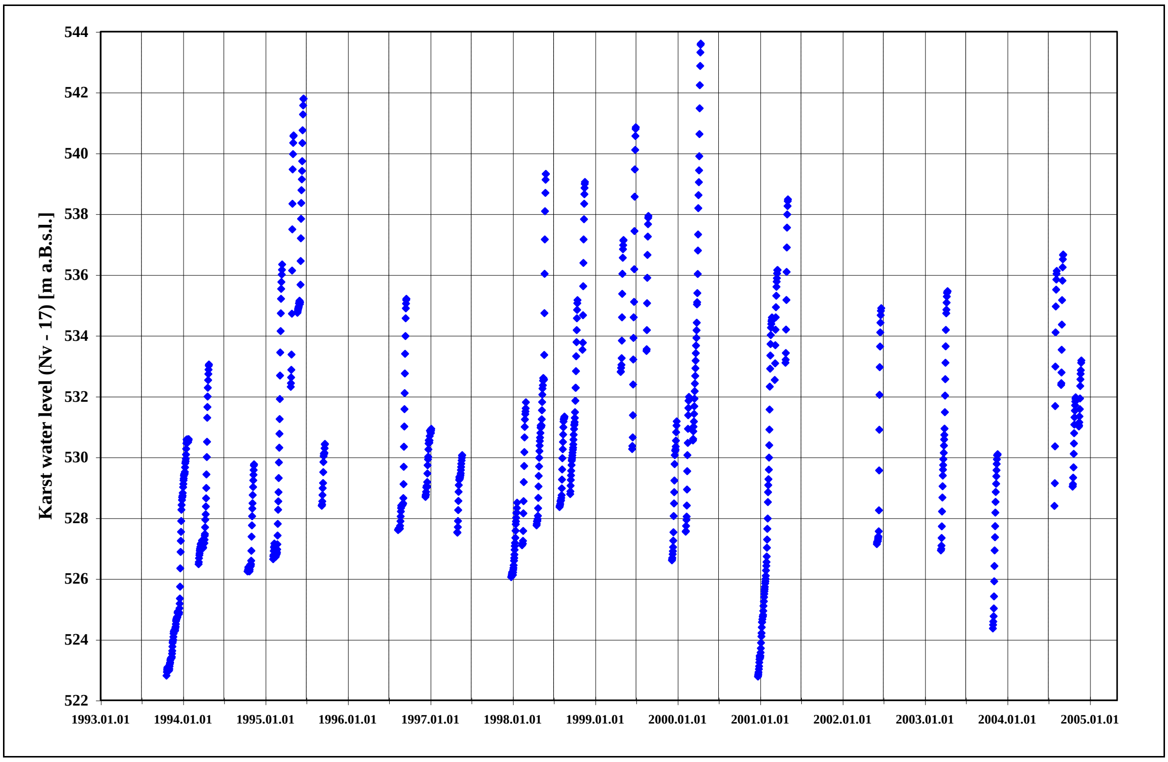


Fig. 3.4.25 Events of more than 2 m water level increase in the Nv-17 karst water monitoring well [Original, 2005]

3.10.3.2. Decrease in the karst water level

Figure 3.4.26 shows all water level decreases that are at least 2 m. (This is about 10 % of the maximum water level fluctuation.) These decreases were not influenced by precipitation, or were influenced only slightly. Although the running of their course is differing from each other, it is within reason to examine them together. The diagram clearly shows that the decreases are much more steep, when the starting level is higher. In year 1993 and 2000, the diminishing water level decrease starting from a low water level can be observed.

At the beginning of this research my opinion was that in 3 or 4 months the Bükk karst almost completely would empty out. But since April 13, 2000, the karst water level in the Bükk has been decreasing continuously, so I was able to record more than 9 months of continuous karst water level decrease. The only reason that this very long dry season and its consequences - the continuous diminishing of the karst water level – were not catastrophic is that the starting karst water level - 543.60 m a.B.s.l., recorded in 13 April, 2000 – was the highest karst water level since October 10, 1992. (So the time frame in which the karst empties out can be very long if the karst water level is very high to start with.)

Nowadays I give my monthly prognosis based on the data recorded here hourly. Based on this data I calculate the daily averages. On ***Figure 3.4.27*** I show a sixth-degree polynom fitted on these values. (Because of the vast amount of data and the high values, I give the fitting values in 12 digit. We can only get exact results with this many decimals. In my monthly report I give prognosis for 30 and for 60 days in expected water levels and water amounts. Of course, the prognosis only correct if no greater than average amount of precipitation is taking place. I will analyze later the term „effective precipitation".)

Naturally there are other ways to determine the decreasing water levels ***[Maucha, 1993; Csige and Lénárt, 2002]***.

I use my own method because of its simplicity, proved reliability and tight correlation, but I always reserve the right for modification to improve accuracy.

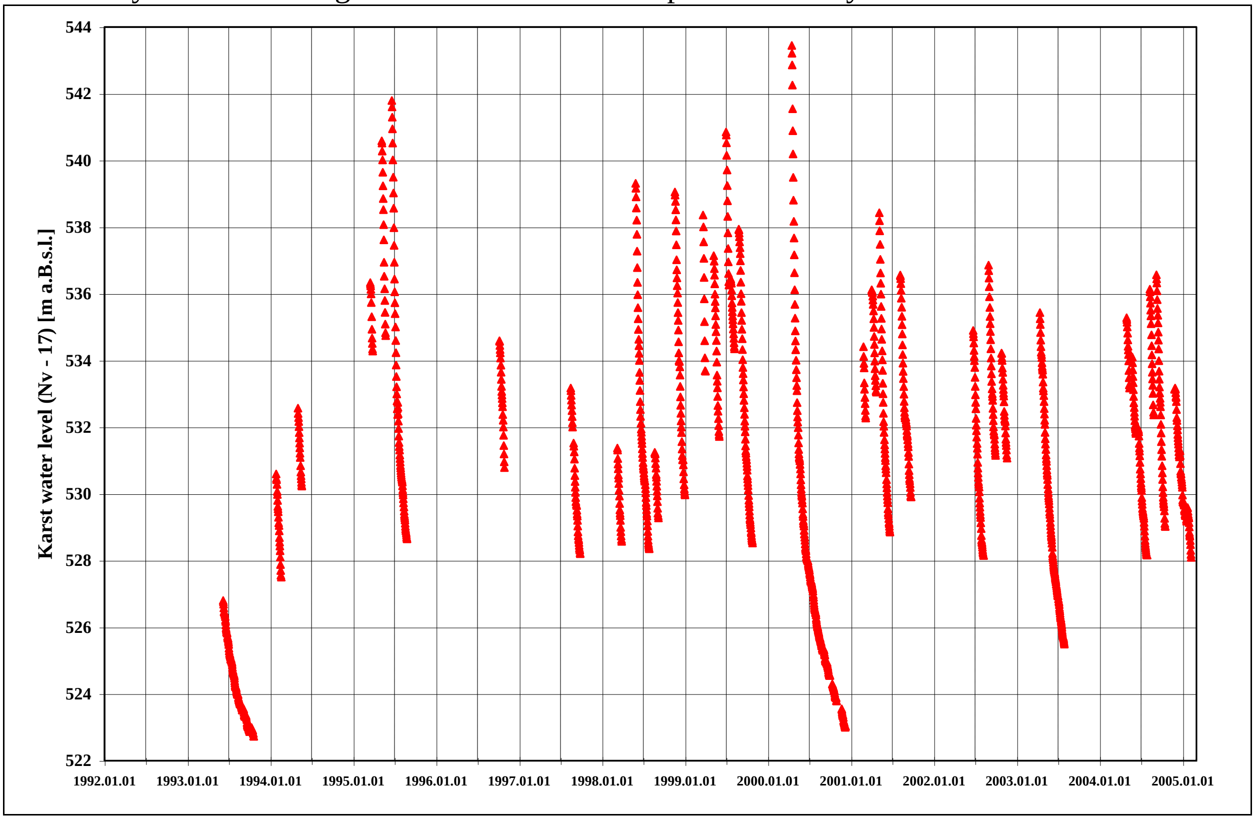


Fig. 3.4.26 Events of more than 2 m water level decreases in the Nv-17 karst water monitoring well [Original, 2005]

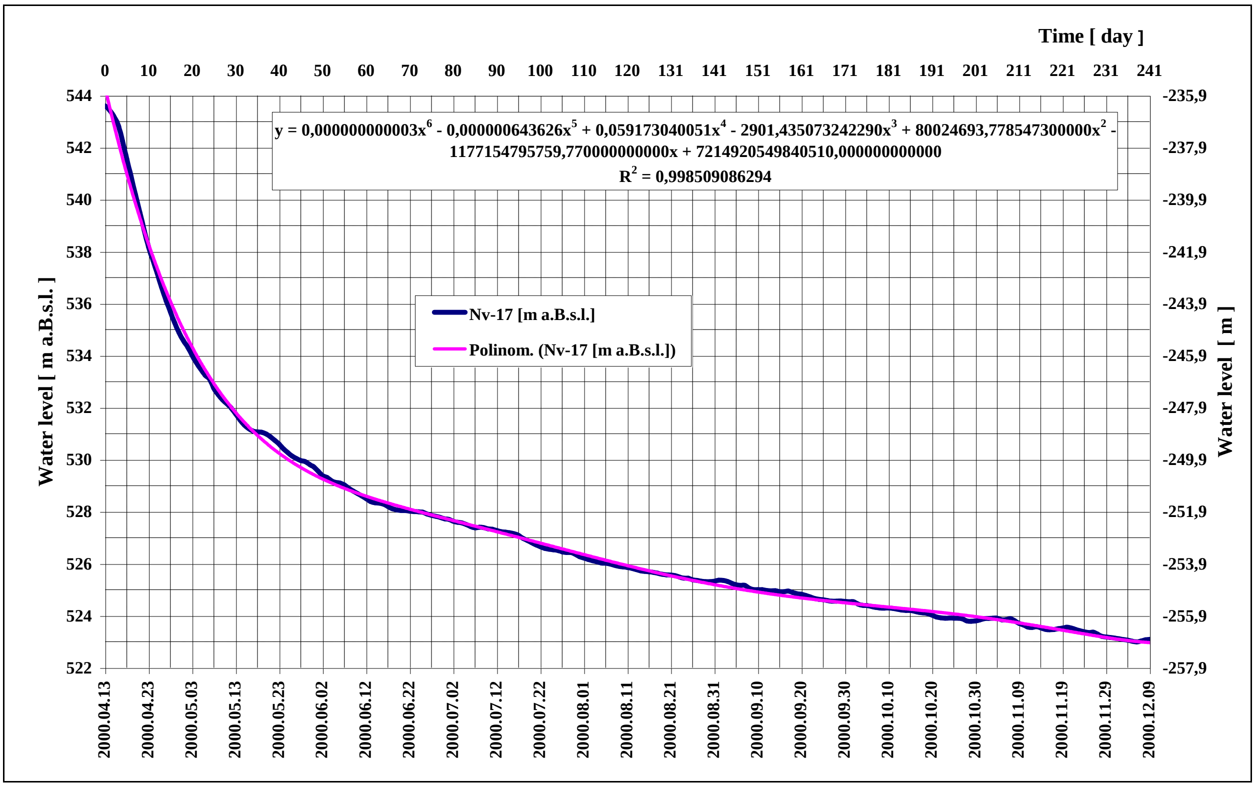


Fig. 3.4.27 The greatest recorded water level decrease, starting April 13, 2000, in the Nv-17 karst water level monitoring well [Original, 2002]

From among the measurements recording the water level decrease starting April 13, 2000, I chose 4 diagrams and compared the diagrams to each other ***[Lénárt, 2002, 2005a; Lénárt et al., 2002] (Table 3.4.II)***.

Table 3.4.II

	Connections	**Difference of the highest water levels**	**Correlation factor concerning of the connections of the water level**
1.	**Nv-17 (=Nv-8) – Sz-5**	543 – 238 = 305 m	0.87
2.	**Nv-17 (=Nv-8) – Szinva spring**	543 – 344 = 199 m	0.77
3.	**Nv-17 (=Nv-8) – Tbp-1**	543 – 381 = 161 m	0.74

In the first case there is a significant impermeable layer between the two measurement sites, in the second case no such layer is known, in the third case there is an impermeable layer again between the two sites ***(Figure 2.2.1)***.

3.10.3.3. Yields and water levels of springs

A number of spring-analysis had taken place in the study area ***(Figures 1.3.5-1.3.6; 2.2.1; 3.4.28-3.4.30)***. Most of the time the yields of the springs were determined, but on other occasions only the fluctuation of the water level in the spring itself could be measured.

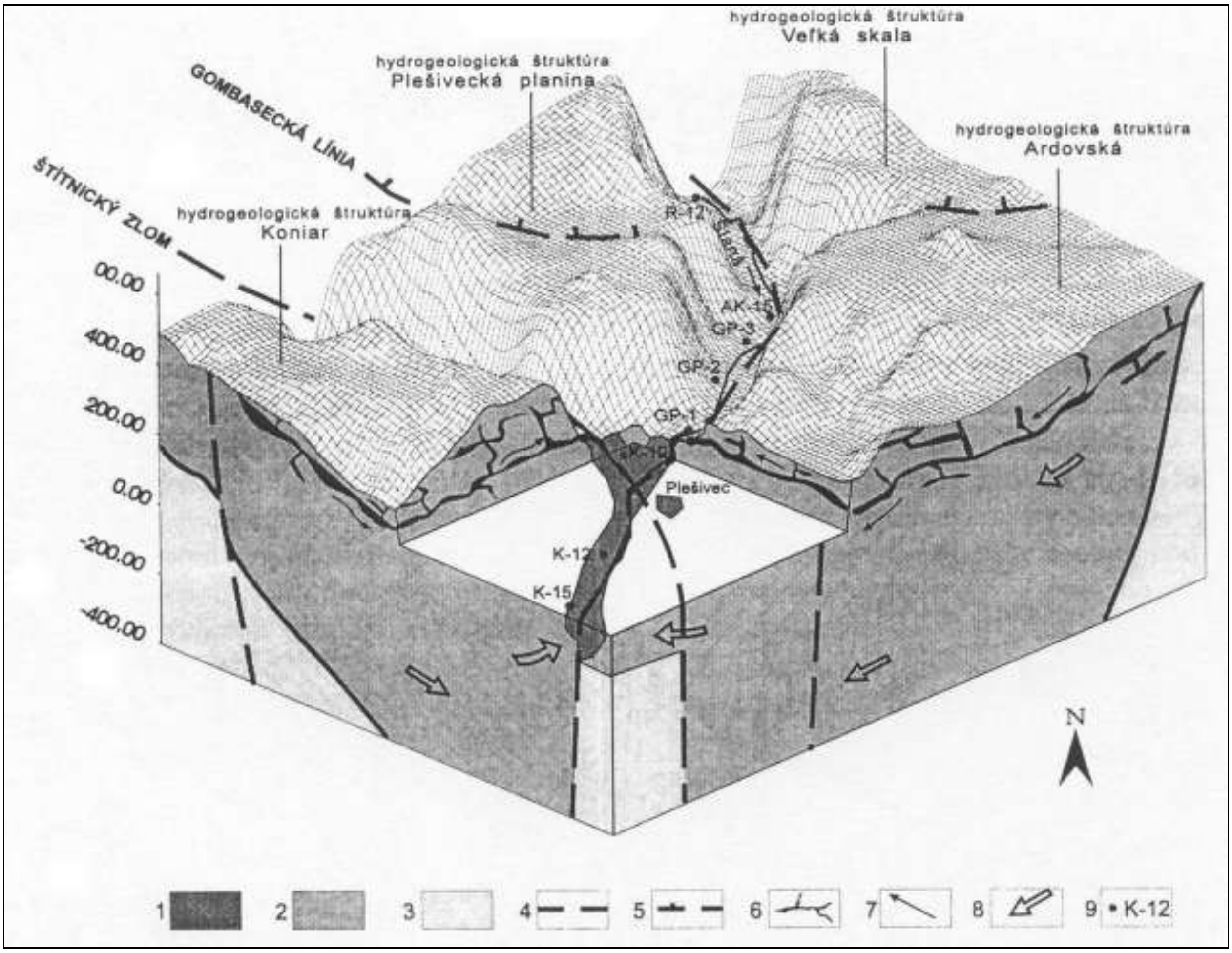


Fig. 3.4.28 Schematic block diagram of the central part of Slovenský kras [Šalagová et al., 1997]
(Legend: 1:Quaternary and Neogen sediments; 2: Middle and Upper Triassic limestones and dolomites of Silica nappe; 3: Lower triassic shales, sandstones, marly limestones and evaporites of Silica nappe; 4: hydrogeologically important tectonic lines; 5: overthrusters; 6: karstic drainage system; 7: direction of groundwater flow in karstic drainage system; 8: direction of groundwater flow in deeper circulation; 9: hydrogeological boreholes)

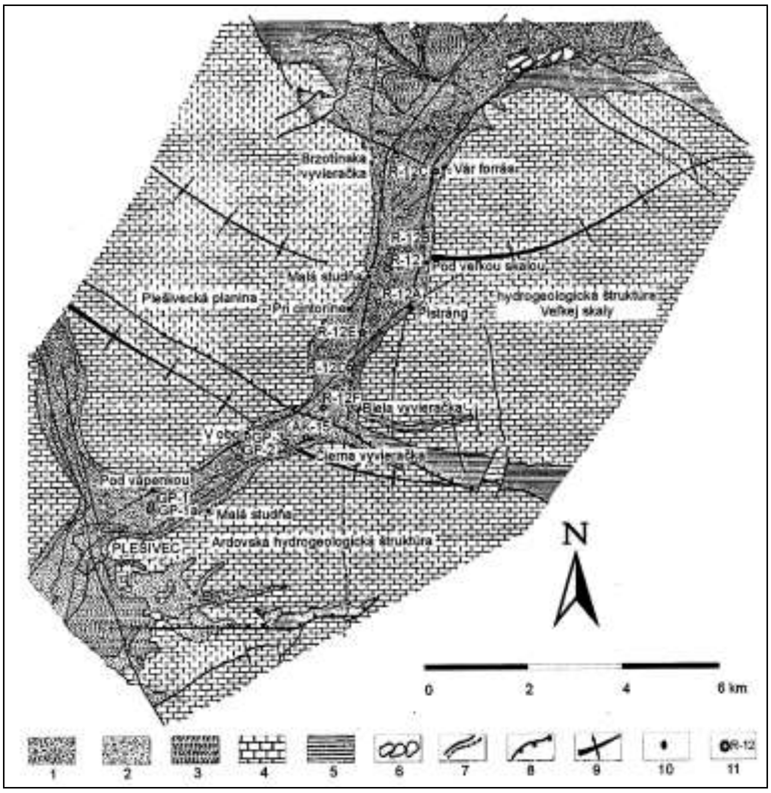


Fig. 3.4.29 Hydrogeological map of the central part of Slovenský kras [Tometz, 2000]
(Legend: 1: Slope sediments; 2Fluvial sediments; 3: Neogen sediments; 4: Middle and Upper Triassic limestones and dolomites; 5: Lower Triassic shales, sandstones, marly limestones and evaporites; 6: fish ponds; 7: faults; 8: overthrusters; 9: synclinal line; 10: springs; 11: hydrogeological boreholes)

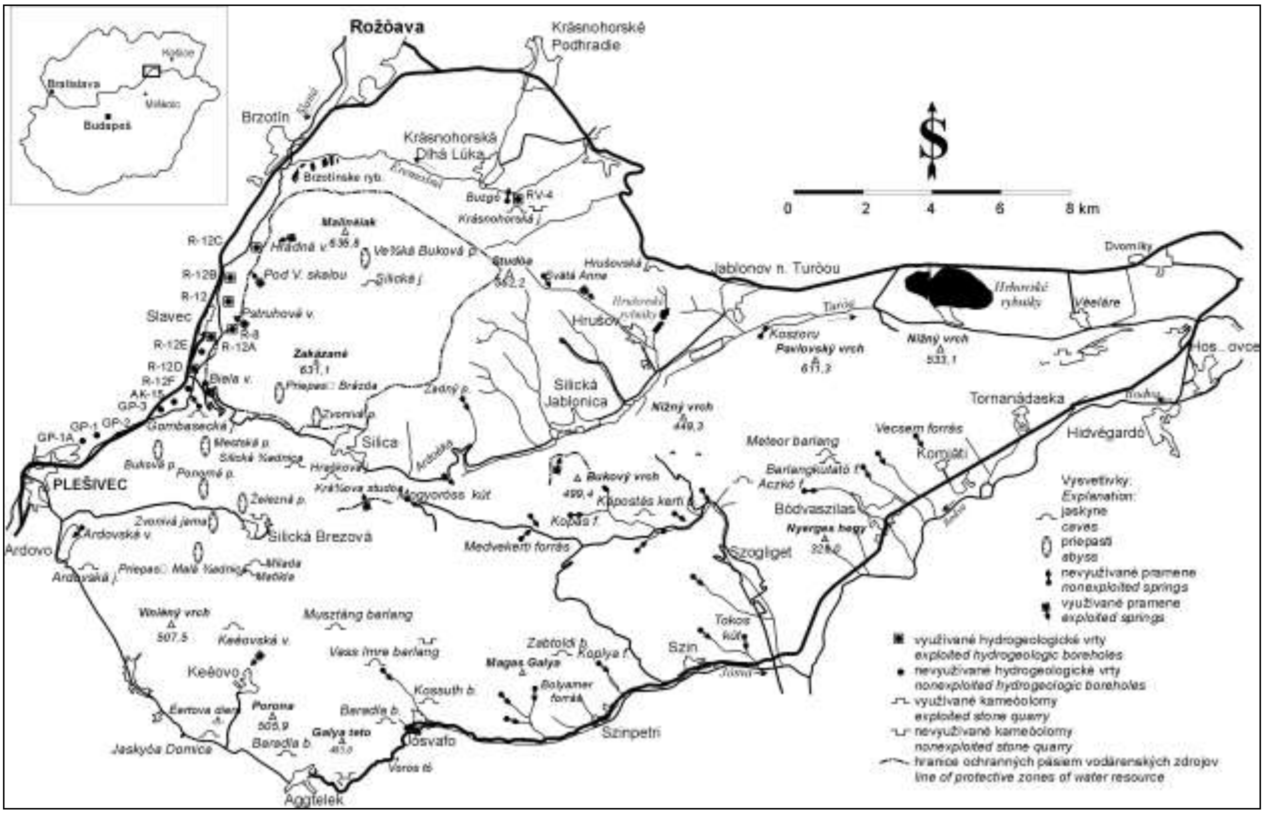


Fig. 3.4.30 Hydrogeological map of the Gemer-Turna (Gömör-Torna) Karst [Lénárt and Tometz, 2004]

Figures 3.4.31-3.4.35 shows a some of the most significant data and results of the measurements that had taken place on the Slovak Karst, based on the work of ***Kullman, 1990 and Tometz, 2000c***.

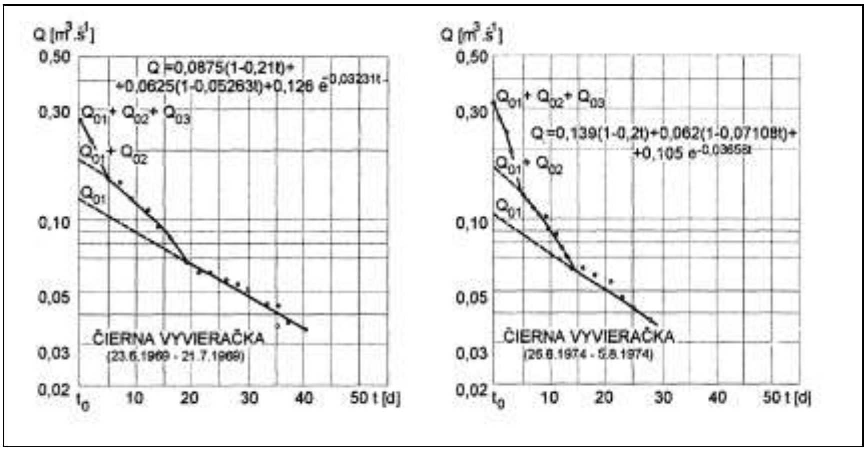


Fig. 3.4.31 Groundwater depletion curve of "Čierna vyvieračka" spring [Kullman, 1990]

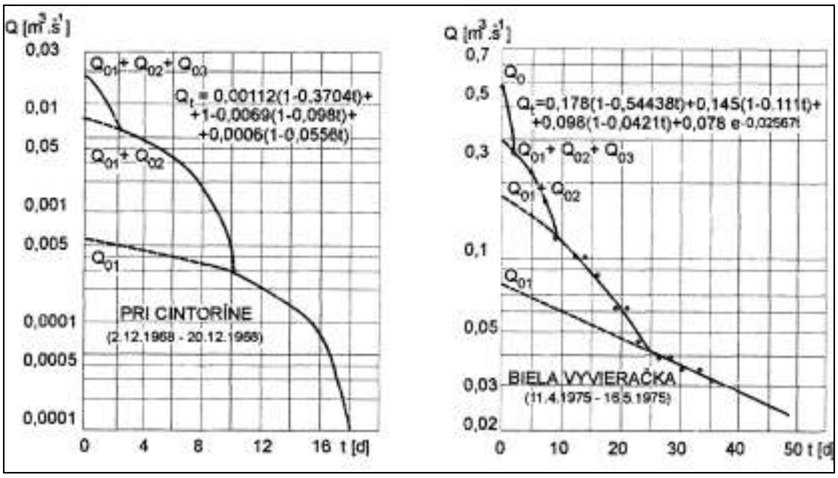


Fig. 3.4.32 Groundwater depletion curve of "Pri cintorine" and "Biela vyvieračka" springs [Kullman, 1990]

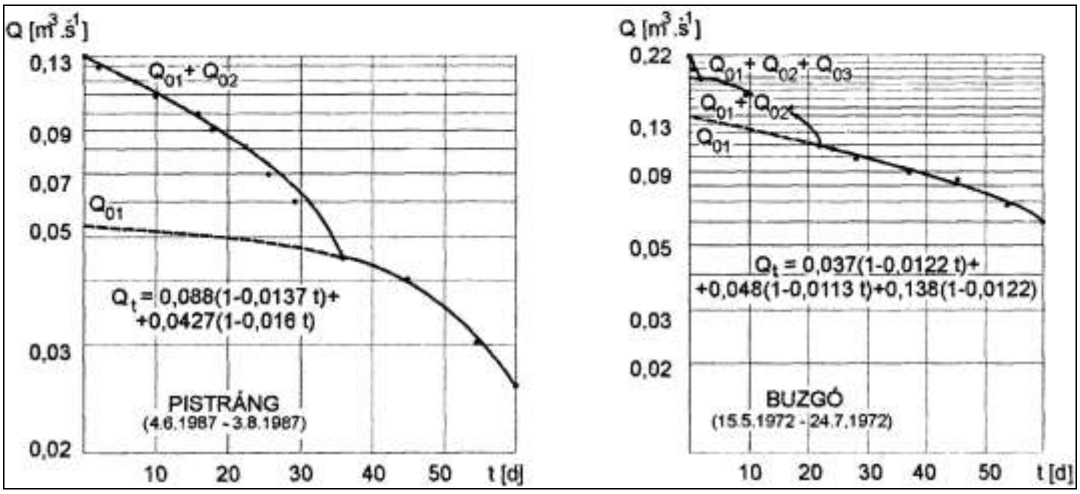


Fig. 3.4.33 Groundwater depletion curve of "Pisztráng" and "Buzgó" springs [Kullman, 1990]

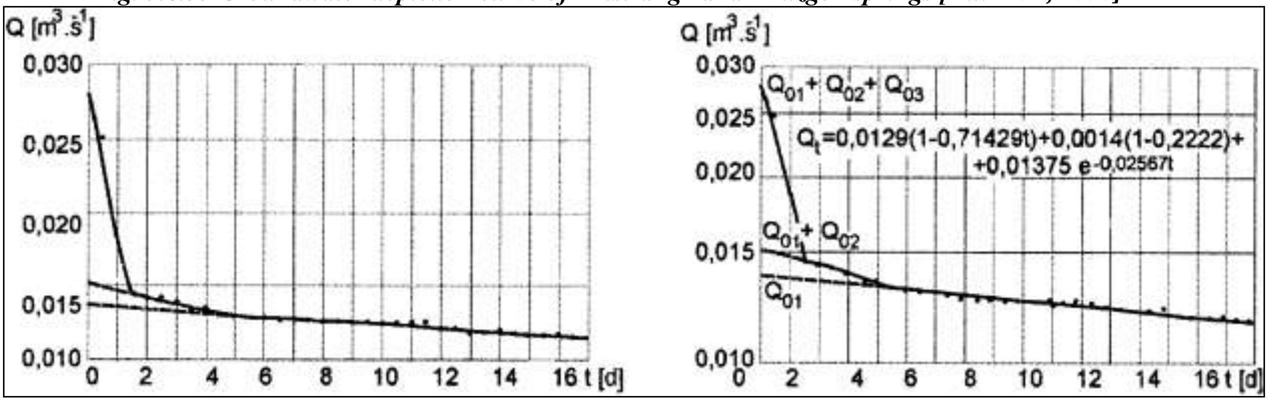


Fig. 3.4.34 Groundwater depletion curve on well R-8 Slavec [Kullman, 1990]

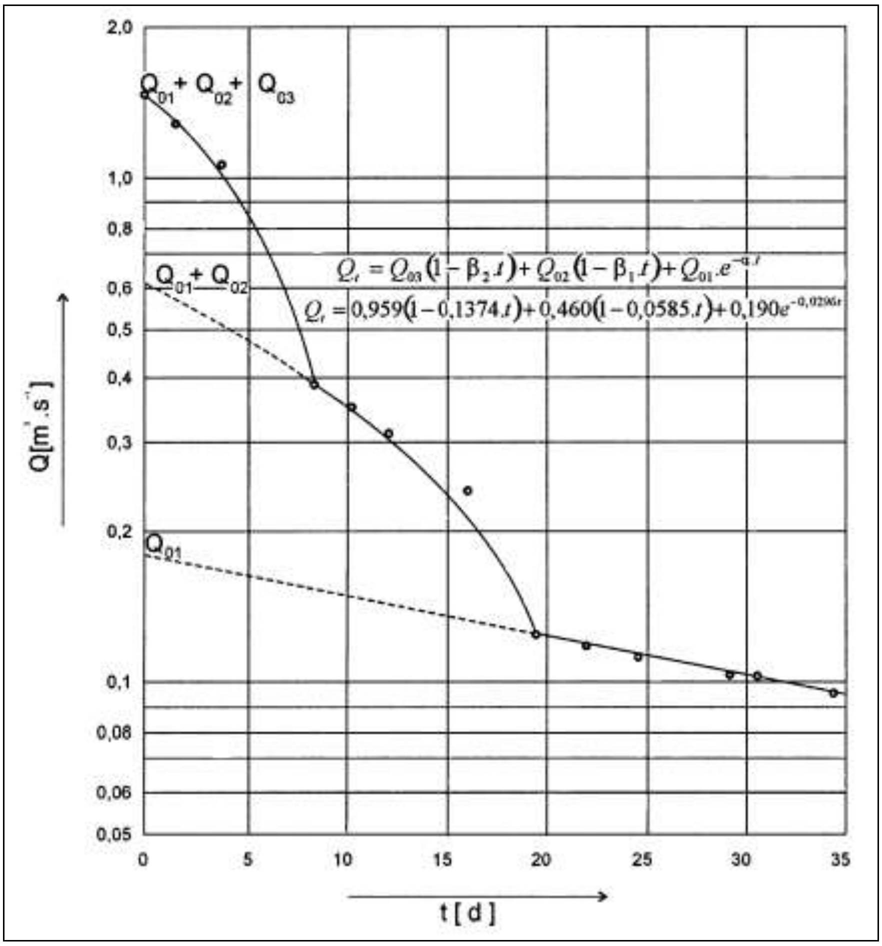


Fig. 3.4.35 The summarized groundwater depletion curve of springs of Veľkej skaly [Tometz, 2000c]

Figures 3.4.36-3.4.42 shows a few typical measurement results of the springs of the Aggtelek Karst, based on the works of ***Maucha, [1998]***. Interesting that Kullman differentiates between maximum 4 phases at the depletion curves while ***Maucha [1993, 1998]*** differentiates 6 of them.

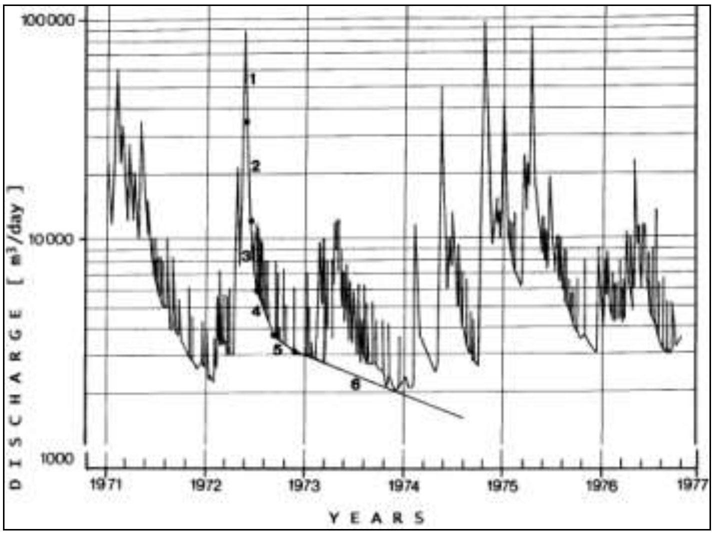


Fig. 3.4.36 Groundwater depletion curve of "Nagy-Tohonya" spring on 1971-1977 [Maucha, 1998]

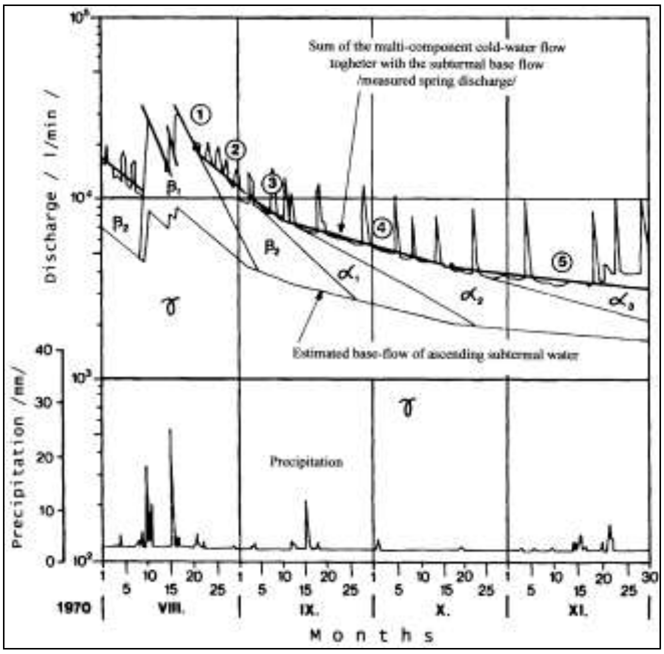


Fig. 3.4.37 Groundwater depletion curve of "Nagy-Tohonya" spring on 1970 [Maucha, 1998]

Fig. 3.4.38 Measuring point of "Nagy-Tohonya" spring [Maucha, 1998; Lénárt, 2005]

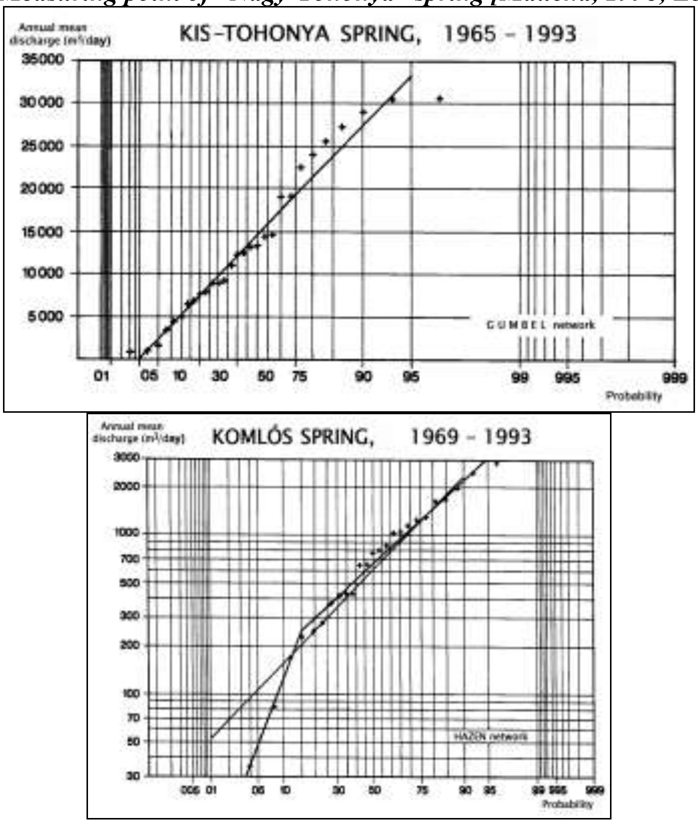


Fig. 3.4.39 Discharge from "Kis-Tohonya" spring 1969-1993 [Maucha, 1998]

Fig. 3.4.40 Discharge from "Komlós" spring 1969-1993 [Maucha, 1998]

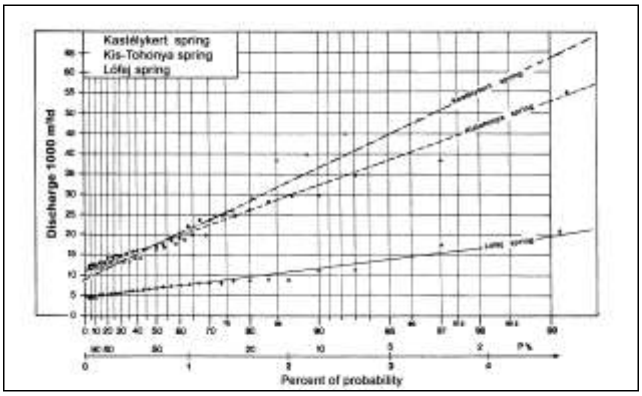


Fig. 3.4.41 Discharge from "Kastélykert", "Kis-Tohonya" and "Komlós" springs [Maucha, 1998]

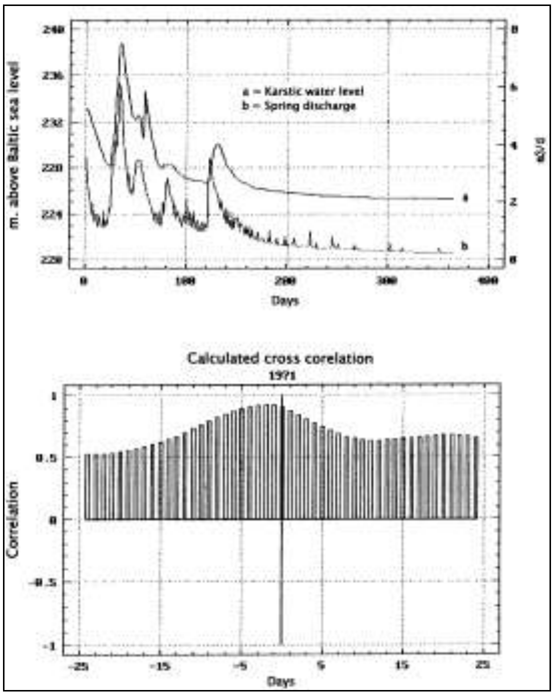


Fig. 3.4.42 Groundwater depletion curve of "Nagy-Tohonya" spring and karst water level of well Jósvafő 1 [Maucha, 1998]

In the beginning of my study there were only the spring measurements. It was followed by the deepening of a number of research boreholes, and these started to function as karst water level monitoring wells. The Karst Water Monitoring Network of the Bükk is mostly operating based on these wells ***(Figure 2.2.1)***, but there are other water level data collection as well, in the shafts of some of the springs. ***Figure 3.4.43*** shows two typical curves that were formed by measurements taken in every 15 minutes. The differences between them are due to the different geological characteristics. The Garadna spring discharges from dolomite and runs downward by itself, the Szinva spring exits from limestone and it is coming upward from down. (***Figures 3.4.9-3.4.12*** helps to compare the two springs. These figures are based on the daily average yields.)

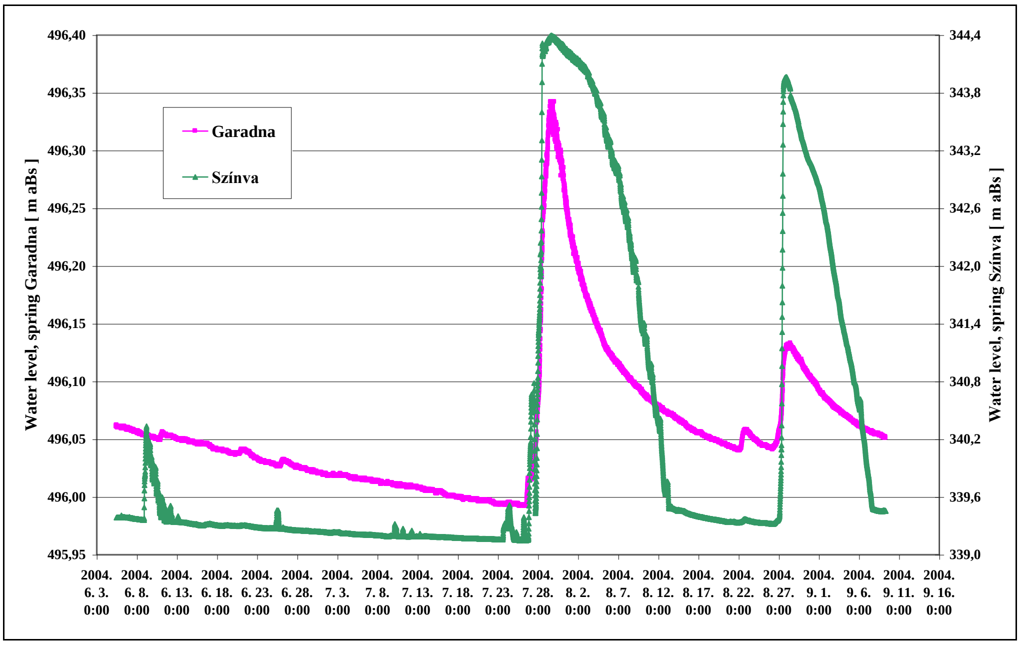


Fig. 3.4.43 Depletion curves of "Garadna" and "Szinva" springs [Original, 2005]

I made an assessment regarding the connection between the water levels measured in the Garadna spring and the yield of the Garadna creek ***(Figure 3.4.44)***. It seems that the increase in the water level of the spring (which also means an increase in the yield) is not followed by a fluctuation of the yield of the creek, as it is recorded at a measuring station about 3 kilometers away from the spring. But In case of a minimal increase in spring yield, there is a significant increase in the yield of the creek. In case of enormous spring yield fluctuation, there is minimal increase in the yield of the creek. Possibly it is caused by the fluctuation of the amount of the water on the surface or of the groundwater, which changes in close connection with the intensity of precipitation. I don't have enough data to make an exact analysis of this scenario.

When I compare the highest water levels of each measurement site, the connection is the tightest In case of great pressure differences; the worst is the connection if the pressure difference is small. In my opinion the karst water system of the Bükk still should be treated as one connected system. Of course the connections of the partial aquifers that are based on morphological, geographical and tectonical reasons can be different.

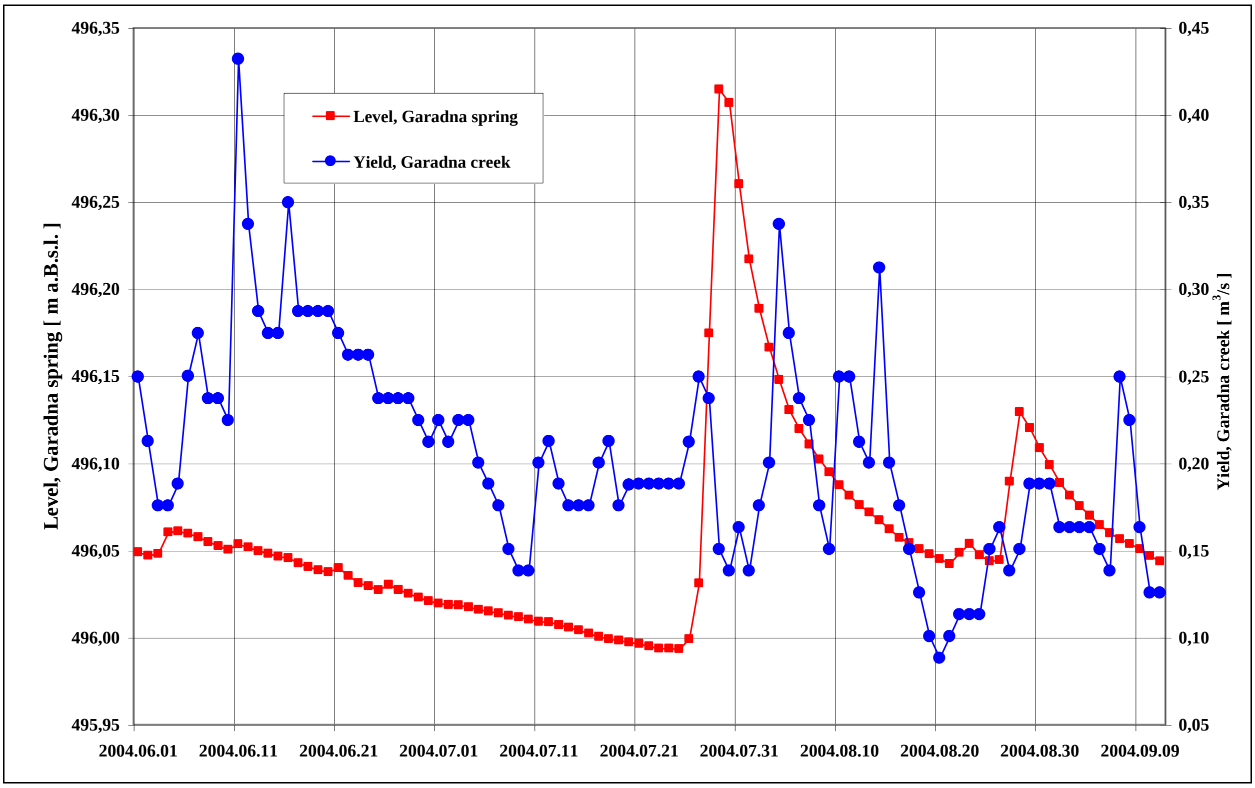


Fig. 3.4.44 Depletion curves of "Garadna" spring and the yield of "Garadna" creek [Original, 2005]

3.10.3.4. The lunisolar effect on the study area

The effect of the Moon (lunisolar effect) on the karst water changes was recorded before by many authors. The first person ever to show the effect of lunar activity in the fluctuation of karst water levels was ***Gerber [1965]***, see ***(Figure 3.4.45)***. This is a historically and methodically important example which shows a one month phase actually very far away from our study area. In it we can find 1 or 2 peaks daily. At New Moon there is negative peak, at Full Moon the water level is increasing.

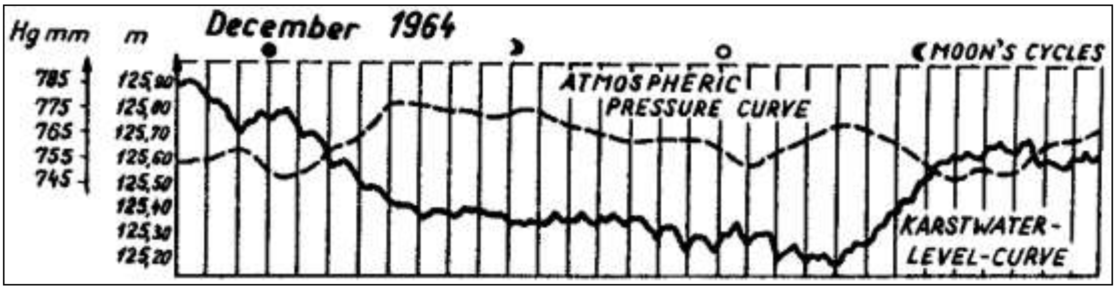


Fig. 3.4.45 Karst water level fluctuations recorded in the well "No. 1. of Tatabánya" [Maucha, 1977, after Gerber, 1965]

Szilágyi [1975] detected 60-80 cm changes in drilled research wells in Recsk; on 140-160 m a.B.s.l. ***Rónaki [1982]*** noted obvious lunisolar effects in the boreholes of Abaliget in the Mecsek. ***Maucha [1977] Figure 3.4.46*** shows the changes of the yield curve of the spring Kis-tohonya as an answer to the lunisolar effect. The two daily peaks that are so typical of the lunisolar gravitational curve can be seen clearly, even though these peaks usually are not of the same value. In this very same source the a small part of the discharge curves of the Kis-tohonya spring and the Vecsem spring could be found. In these curves, 2 or 4 peaks can be read daily ***(Figures 3.4.47-3.4.48)***.

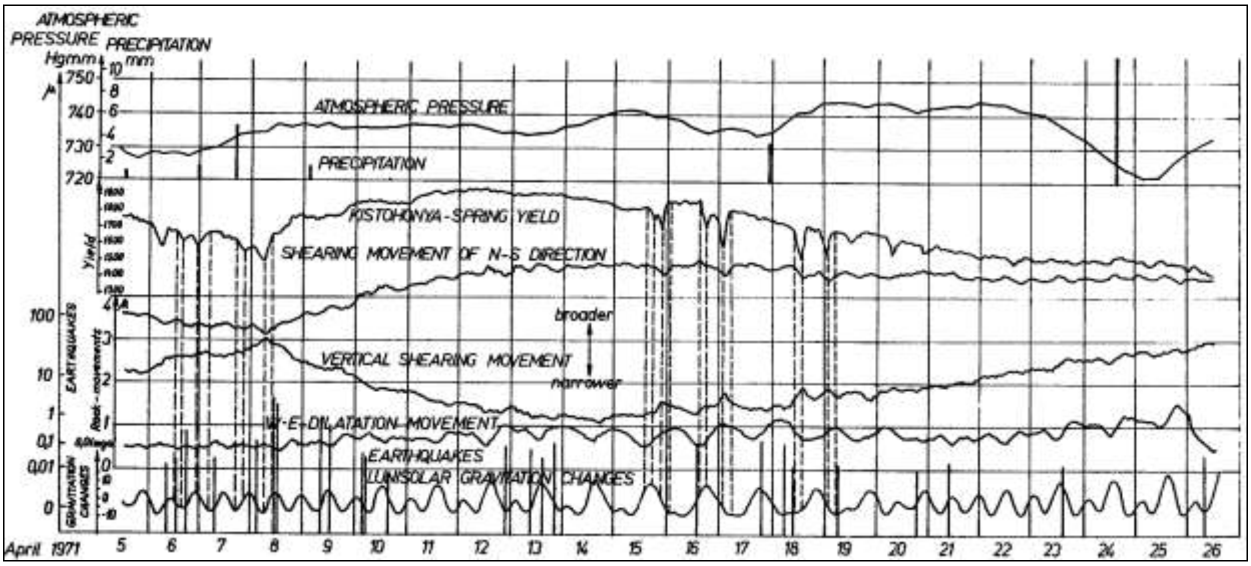
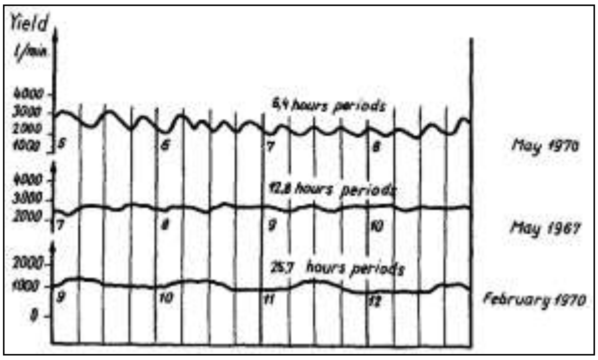


Fig. 3.4.46 The lunisolar effect in Jósvafő, "Kis-Tohonya" spring and "Vass Imre" cave [Maucha, 1977]



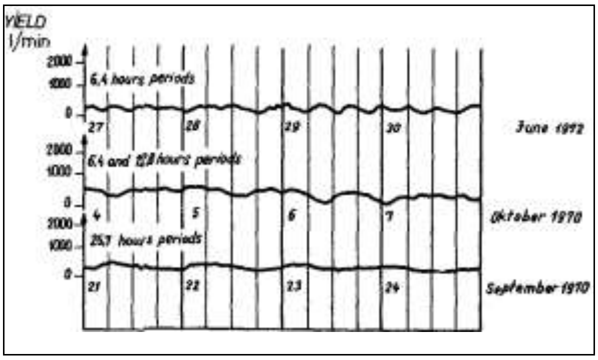


Fig. 3.4.47 The lunisolar effect in Jósvafő, "Kis-Tohonya" spring [Maucha, 1977]
Fig. 3.4.48 The lunisolar effect in Bódvaszilas, "Vecsem" spring [Maucha, 1977]

Maucha [1995, 1998] (Figure 3.4.49) recorded obvious 1-2 cm changes in the karst water level monitoring No. 1 borehole in Jósvafő at 225 m a.B.s.l.. (Must be noted that it was the Jósvafő Karst Research Station that developed a device for in-cave recording of the dilatation changes of rock. During his research the lunisolar effect was detected in the springs of Jósvafő.)

In case of the springs, we can see that in certain cases not 2, but 4 peaks per day can be recognized. (On ***Figure 3.4.54*** we can see that even on more than one occasion, but obviously this cannot be ascribed to the lunisolar effect.) We can see an example to this on ***Figure 3.4.50***, based on the work of ***Maucha, 1998***.

The lunisolar effect is confirmed in the Bükk by my measurements. A relationship can be shown depending on the depths of the wells in the Bükk. The periodicity is 12 hours 55 minutes, but this might need to be made more accurate. (At a moment we are recording comparison measurements in every 15 minutes in the karst water level monitoring wells of the

Bükk, Recsk and Nyírség in order to refine the lunisolar effect, but I will not analyze the latter in this paper.)

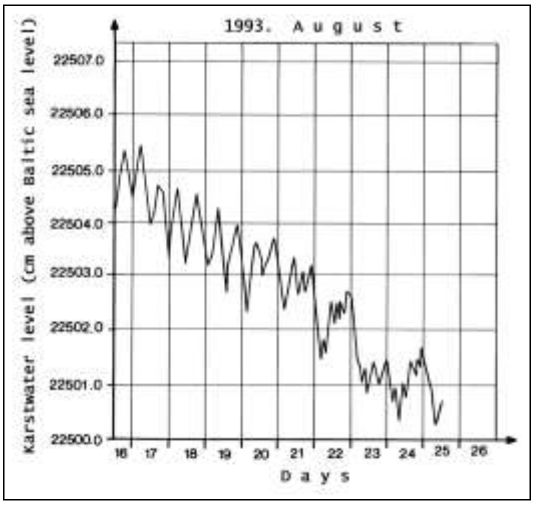


Fig. 3.4.49 The lunisolar effect in "Jósvafő-F1" karst water level monitoring well [Maucha, 1995, 1998]

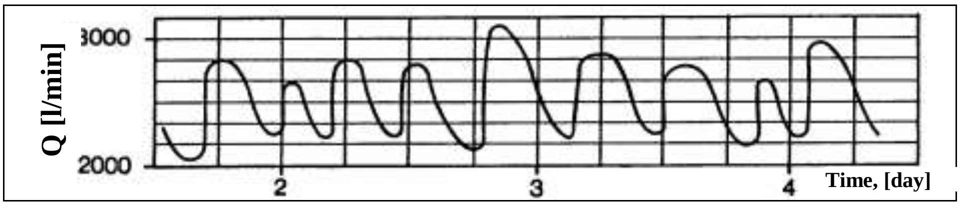


Fig. 3.4.50 The lunisolar effect in Jósvafő, "Kis-Tohonya" spring (2-4.05.1970) [Maucha, 1998]

According to the interpretation, the greatest change can be observed in the karst water level monitoring wells that are situated at the base of the mountain. The lowest changes can be found in the karst water monitoring wells of the plateau (Nv-17; Tbp-1) but still a few centimeters. The lowest changes are in the springs that have large free cubic content and are captive for water production, situated at the edge of the mountain.

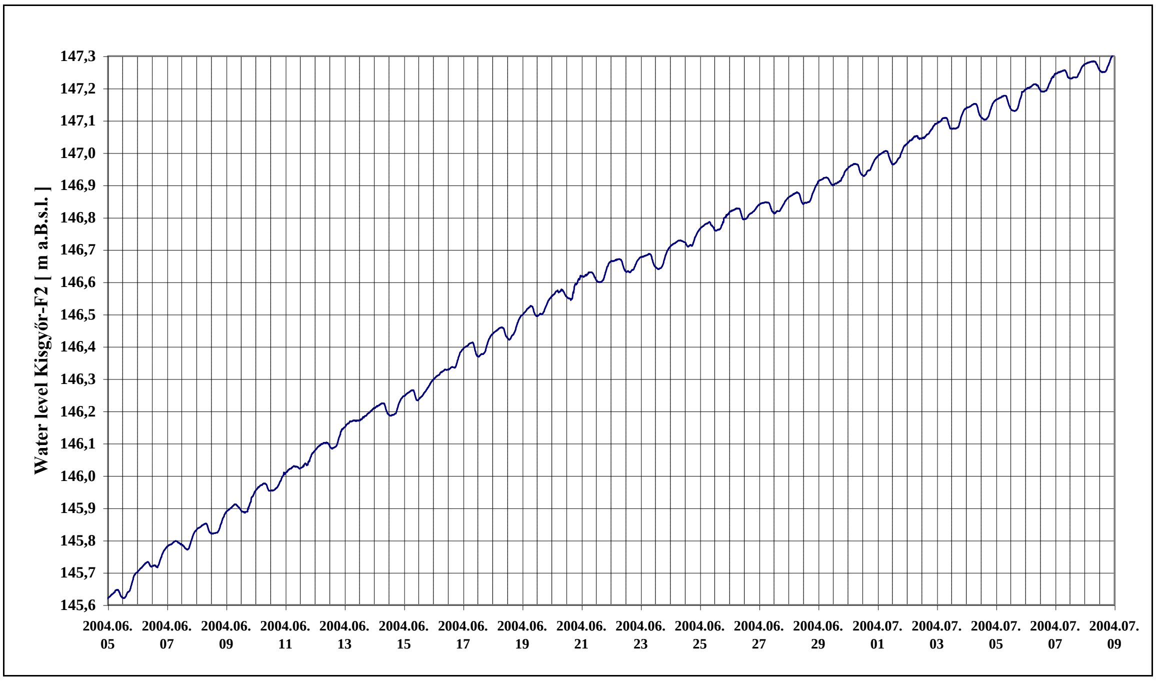


Fig. 3.4.51 The lunisolar effect in Kisgyőr,"F2" karst water level monitoring well [Original, 2005]

Some of the most significant data of the Bükk research will be introduced in the following, based on my own measurements. Definite lunisolar effect appears, that can be followed for a long time, with a water level increase and with peaks that are drawn apart ***(Figure 3.4.51)***.

The following curve shows the lunisolar effect where it can be followed for a long time, very definite in small fluctuation phases. In phases of rapid changes it is more difficult to recognize. Sharp peaks can be observed ***(Figure 3.4.52)***.

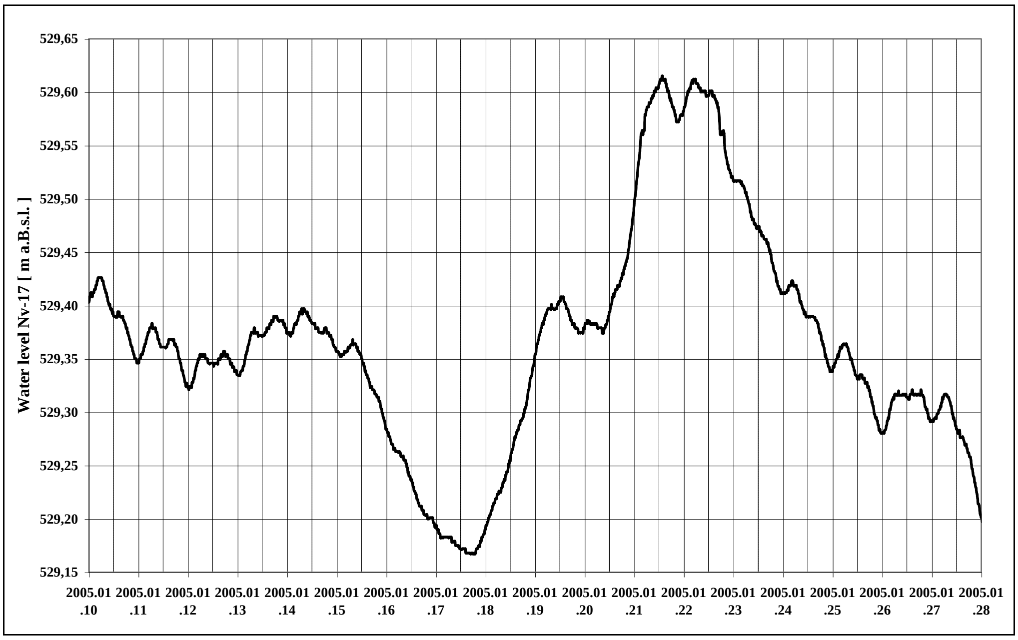


Fig. 3.4.52 The lunisolar effect in Nagyvisnyó," Nv-17" karst water level monitoring well, situated at the centre of the mountain [Original, 2005]

Definite lunisolar effect, which can be followed for a long time, with a water level decrease. The upper part of the curve has double; the lower part of the curve has single peaks ***(Figure 3.4.53)***.

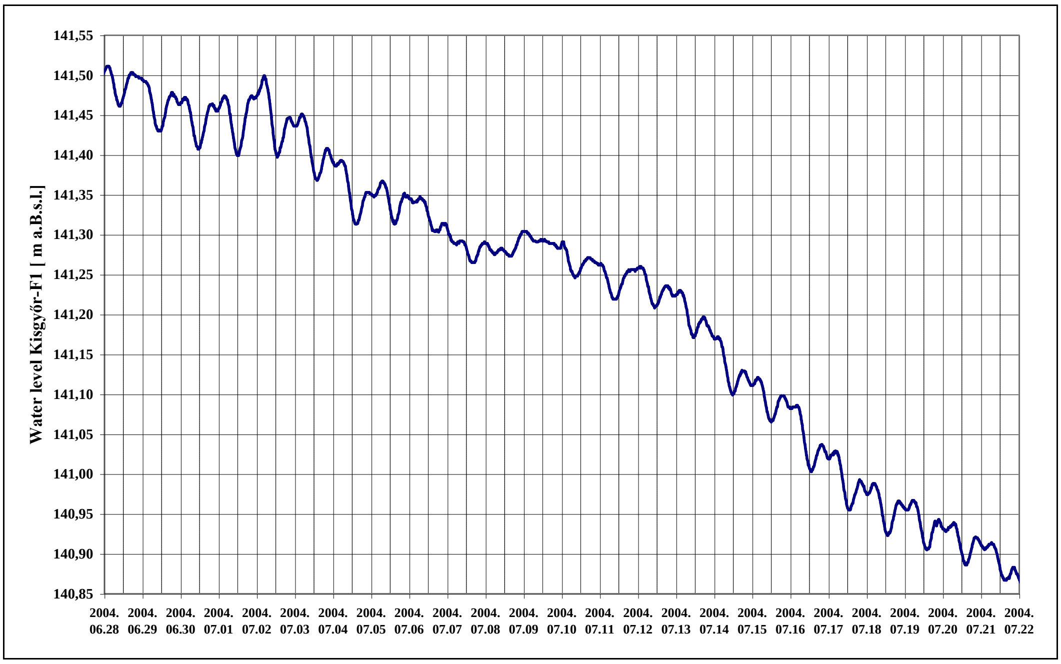


Fig. 3.4.53 The lunisolar effect in Kisgyőr "F1" karst water level monitoring well [Original, 2005]

Barely recognizable long-term lunisolar effect with rapidly decreasing water levels. Other unknown effects are present as well ***(Figure 3.4.54)***. (***Maucha [1995, 1998]*** displayed a very similarly "intensive" curve. One example of this is shown in ***Figure 3.4.50***).

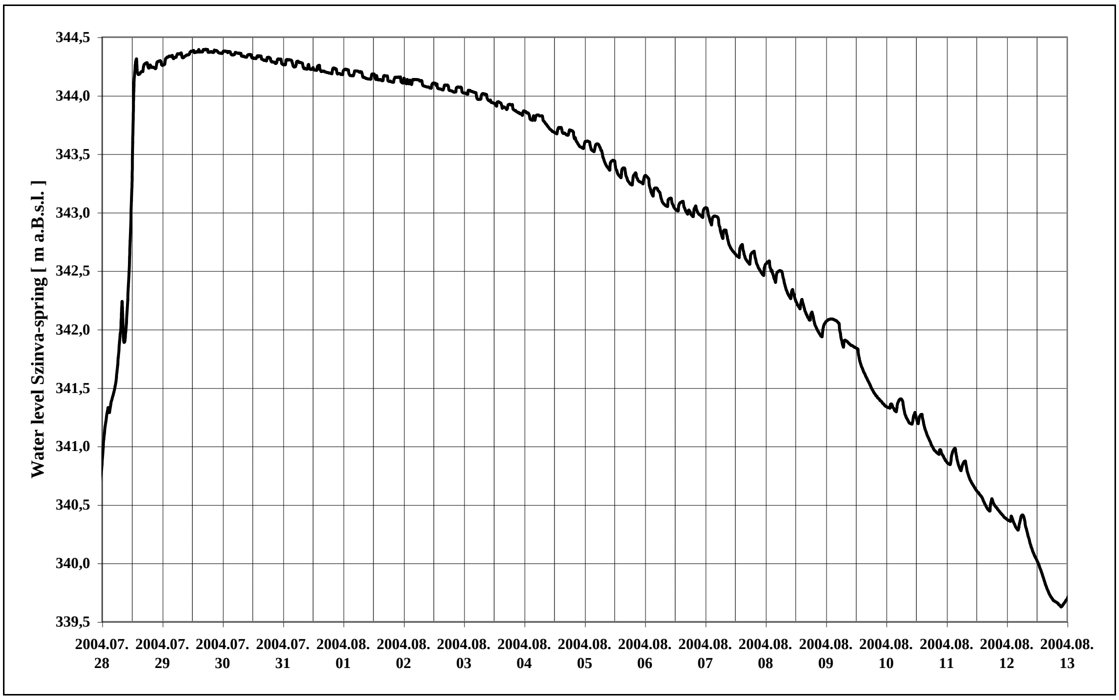


Fig. 3.4.54 The lunisolar effect in Miskolc-Lillafüred, "Szinva" karst water level monitoring spring, situated at the big valley of the mountain [Original, 2005]

Short term, well defined lunisolar effect, in case of almost even water level (***Figure 3.4.55)***.

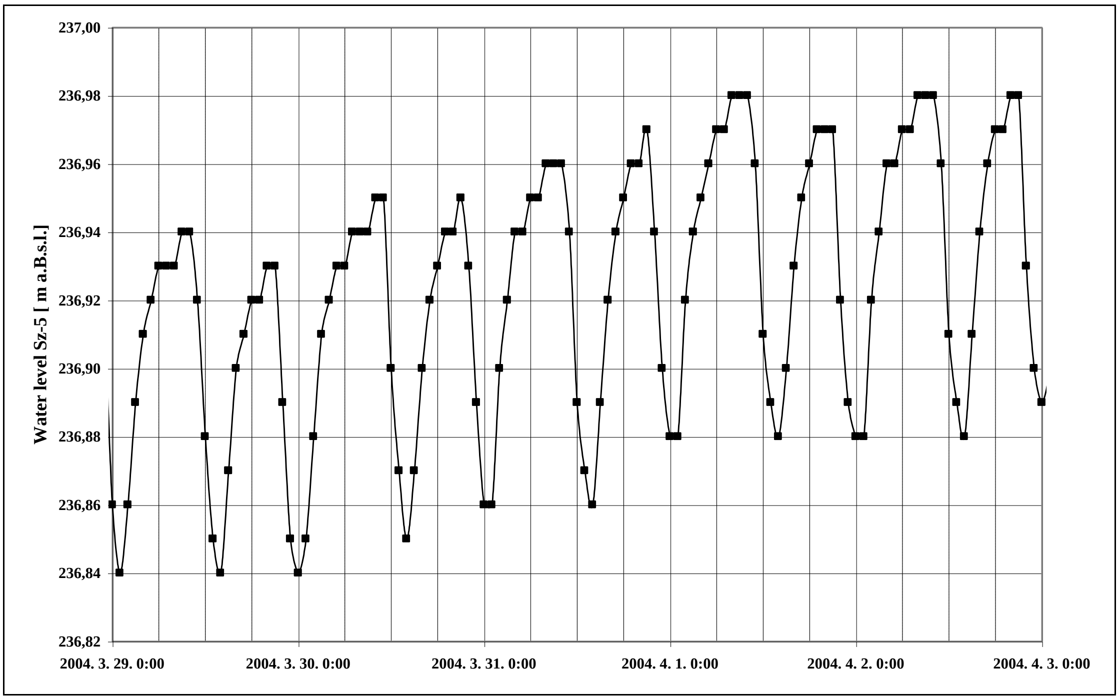


Fig. 3.4.55 The lunisolar effect in Felsőtárkány,"Sz-5" karst water level monitoring well, situated at the edge of the mountain [Original, 2005]

Short-term, well-defined lunisolar effect in case of rapidly increasing water level ***(Figures 3.4.56-3.4.57)***.

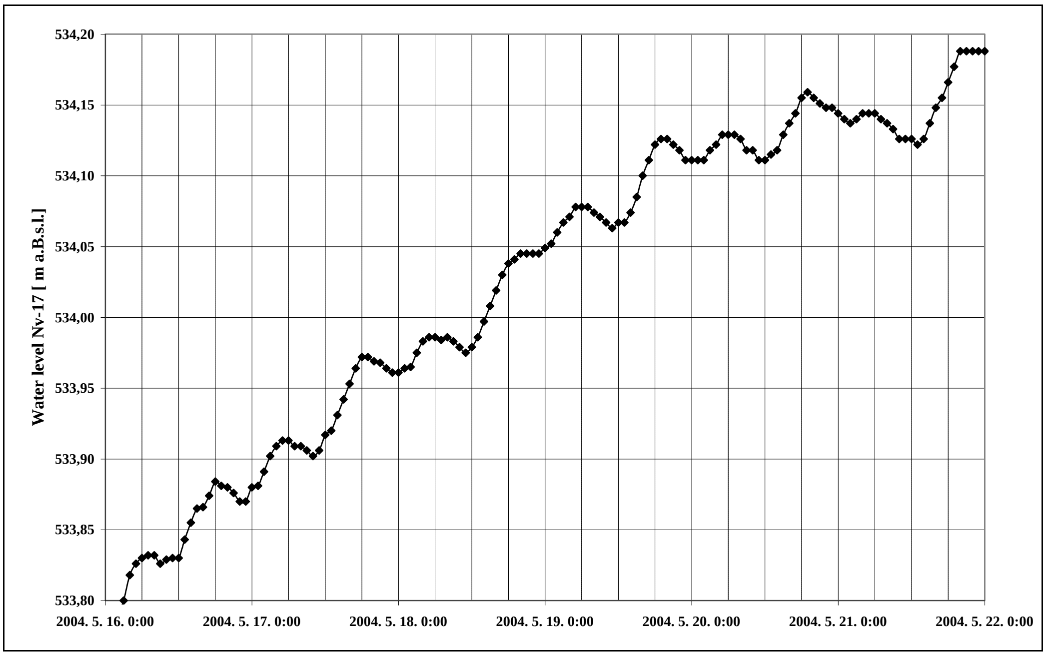


Fig. 3.4.56 The lunisolar effect in Nagyvisnyó, "Nv-17" karst water level monitoring well, situated at the centre of the mountain [Original, 2005]

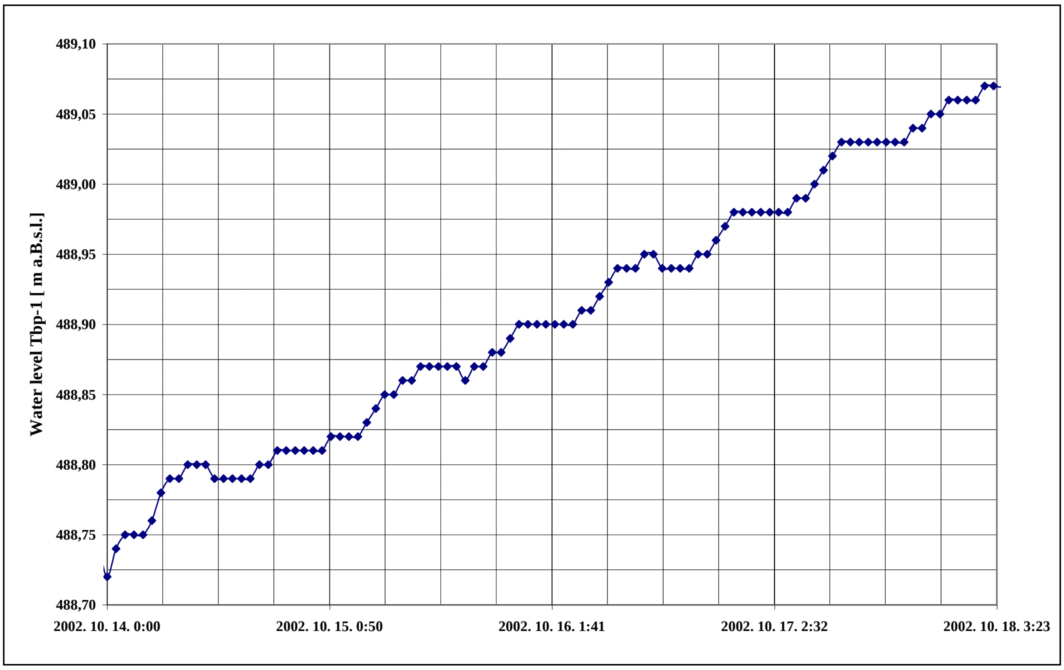


Fig. 3.4.57 The lunisolar effect in Répáshuta, "Tbp-1" karst water level monitoring well [Original, 2005]

On the following figures I had marked some of the most typical points of the way of the Sun and on one figure I had marked certain points of the way of the Sun. It is clearly visible in the water level monitoring boreholes that the rising and the setting of the Moon is accompanied by water level increase. When the Moon is on the highest point of its orbit, the water level decreases. (This decrease in the water level can be explained by the movement of the rocks. The degree of drawing apart is the biggest at that time, so the water level decreases ***Figures 3.4.58-3.4.61***. On ***Figure 3.4.61*** we indicated the air pressure values as well, but the change doesn't seem to be very significant. It should be noted that this data comes from a thermal karst water well, which is pumped; the data was taken in a period of time when there was no production in the well due to technical reasons.)

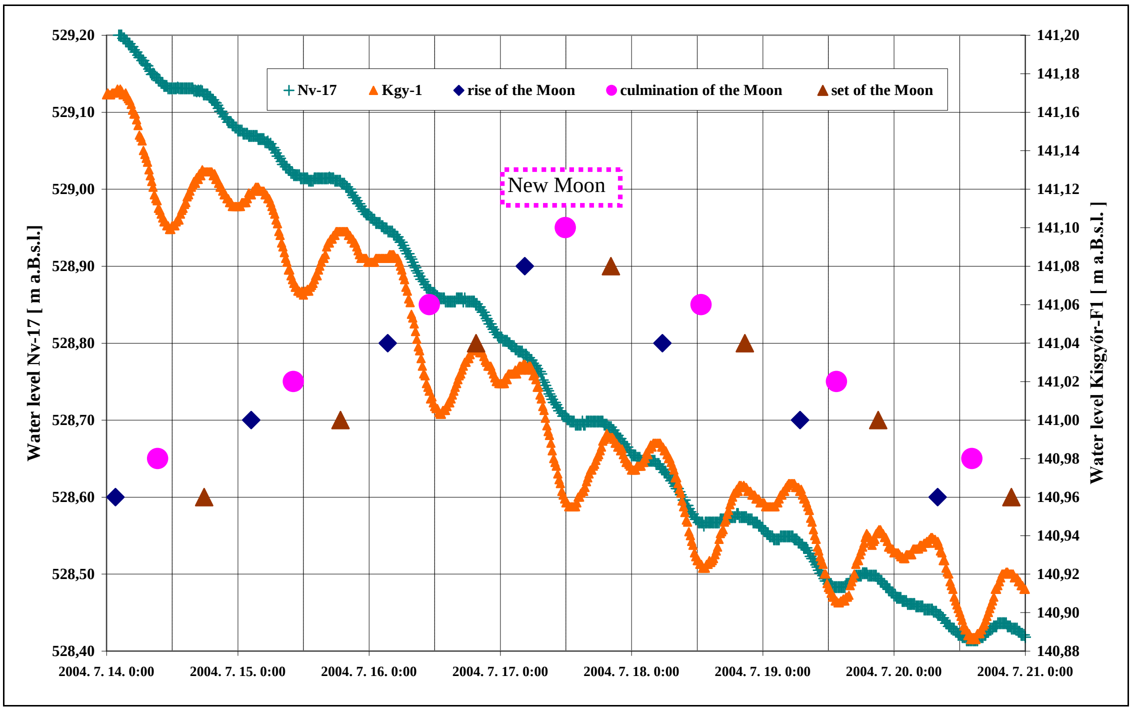


Fig. 3.4.58 The lunisolar effect at New Moon in Nagyvisnyó,"Nv-17" and Kisgyőr, "F1" karst water level monitoring well [Original, 2005]

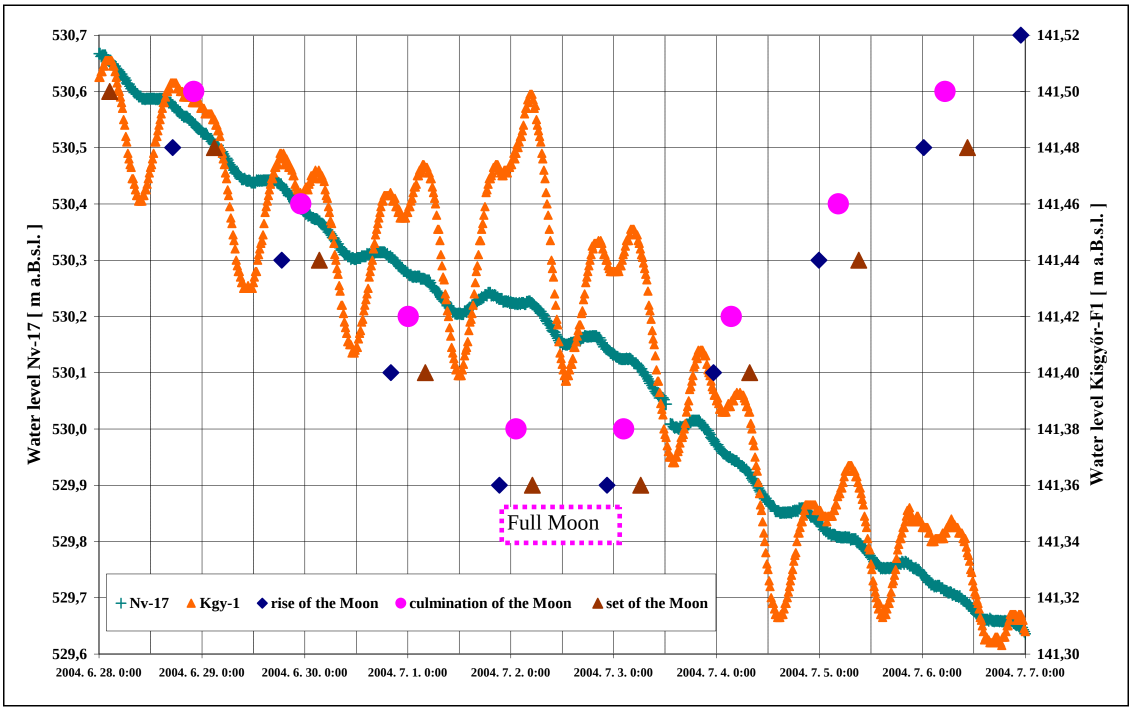


Fig. 3.4.59 The lunisolar effect at Full Moon in Nagyvisnyó, "Nv-17" and Kisgyőr, "F1" karst water level monitoring well [Original, 2005]

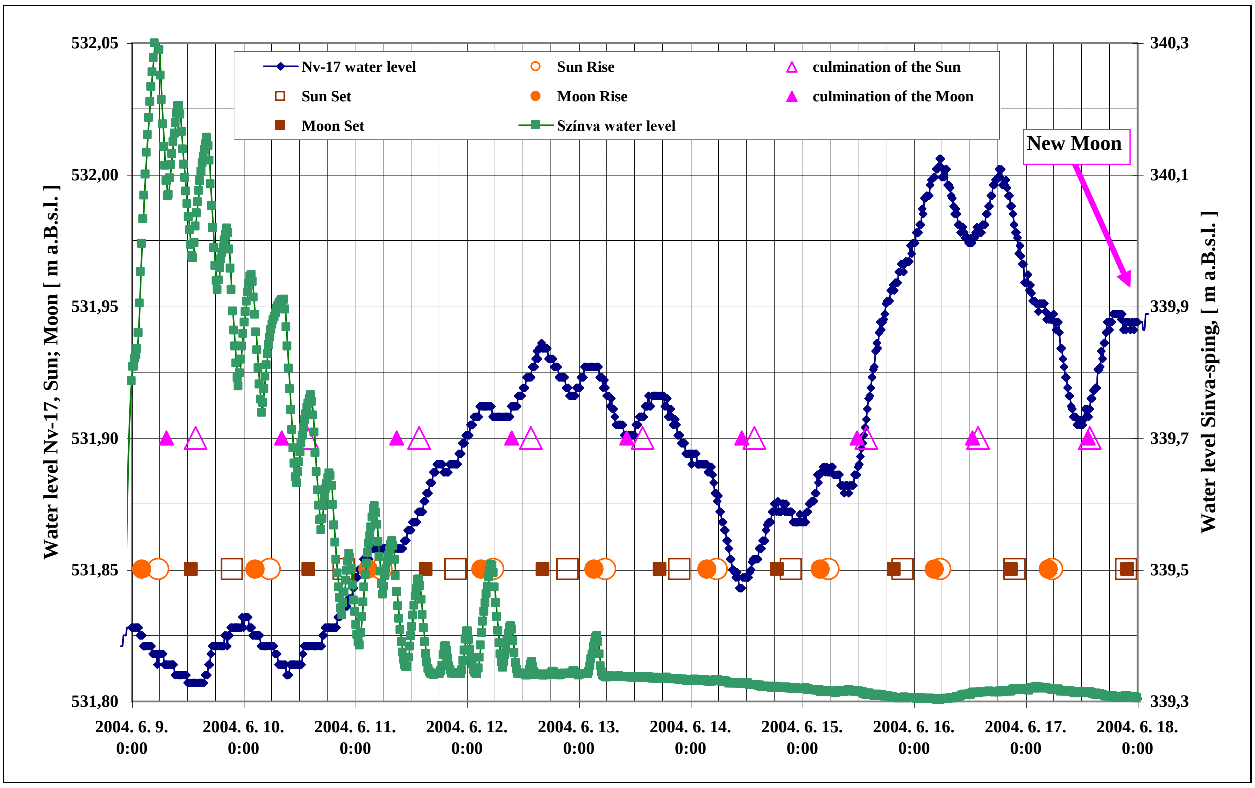


Fig. 3.4.60 The lunisolar effect at New Moon in Nagyvisnyó, "Nv-17" karst water level monitoring well and spring "Szinva" [Original, 2005]

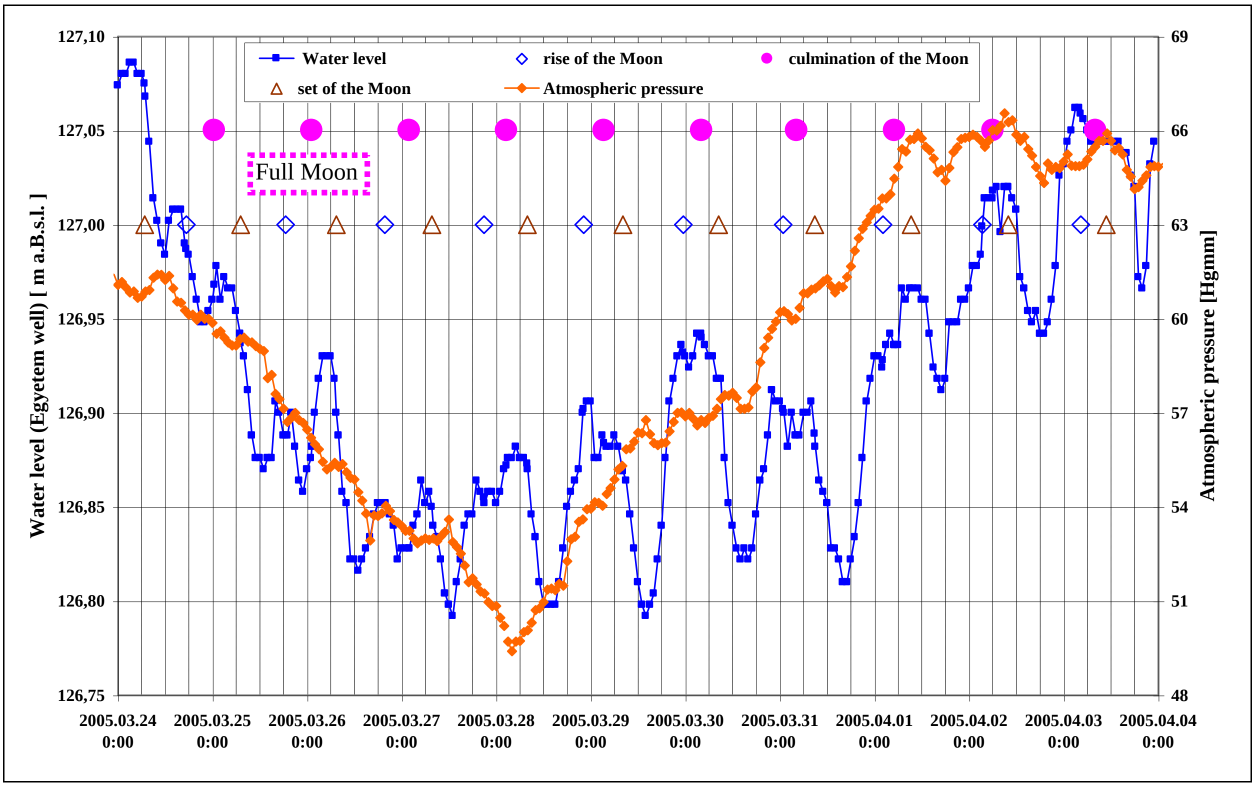


Fig. 3.4.61 The lunisolar effect at Full Moon in Miskolc, "Egyetem" well and atmospheric pressure [Original, 2005]

Spectral data analyses were applied to examine the possible periodicity in the fluctuation of regularly measured water level data. The analyses were made with an analytical version of the Discrete Fourier Transformation (DFT). ***Figures 3.4.62-3.4.63*** show the relative amplitude spectrums of water level data measured at different monitoring stations (Nagyvisnyó and Szinva in the Bükk Mountains, Shaft I. and II. close to Recsk in the Mátra region). The amplitude spectrums demonstrate the hydraulic connectivity between the monitoring sites in the Bükk or the Mátra Mountains ***(Figures 3.4.62a and 3.4.63)***. The differences between the whole spectrums derived from the Bükk and Mátra Mountains prove that the hydraulic connectivity between the two mountain flow systems is rather limited. On the other hand, if we consider the shorter periods in the obtained spectrum ***(Figure 3.4.62b)***, the classical luni-solar effect on the karst water levels can also be recognized at 12 and 24 hours.

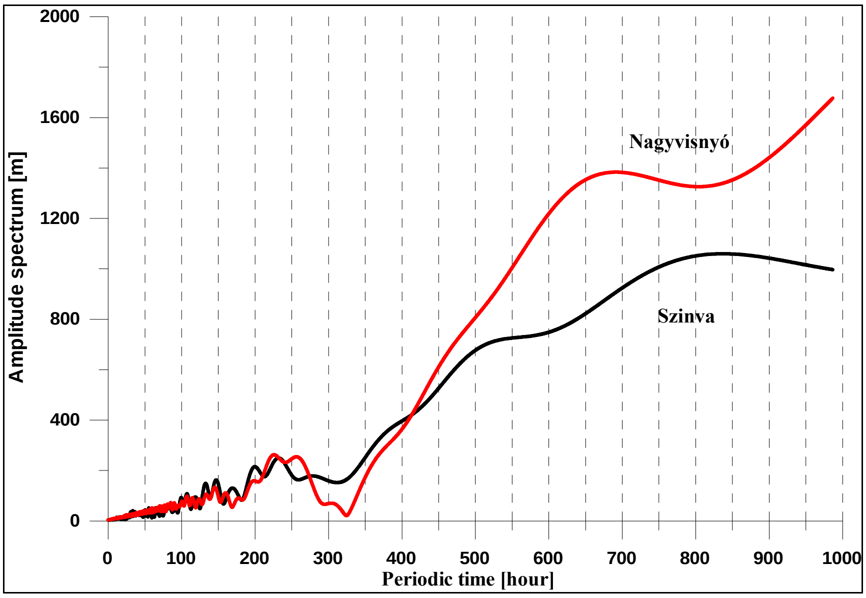


Fig. 3.4.62a Amplitude spectrums of measured water level data (Bükk Mountains) [Szucs and Nyari, 2005]

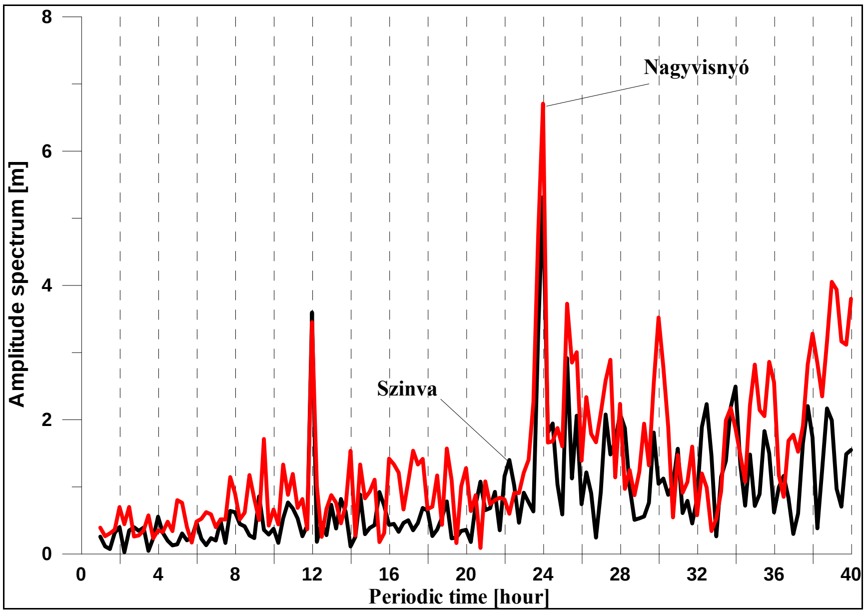


Fig. 3.4.62b Amplitude spectrums of measured water level data (tidal effects at 12 and 24 hours,

Bükk Mountains) [Szucs and Nyari, 2005]

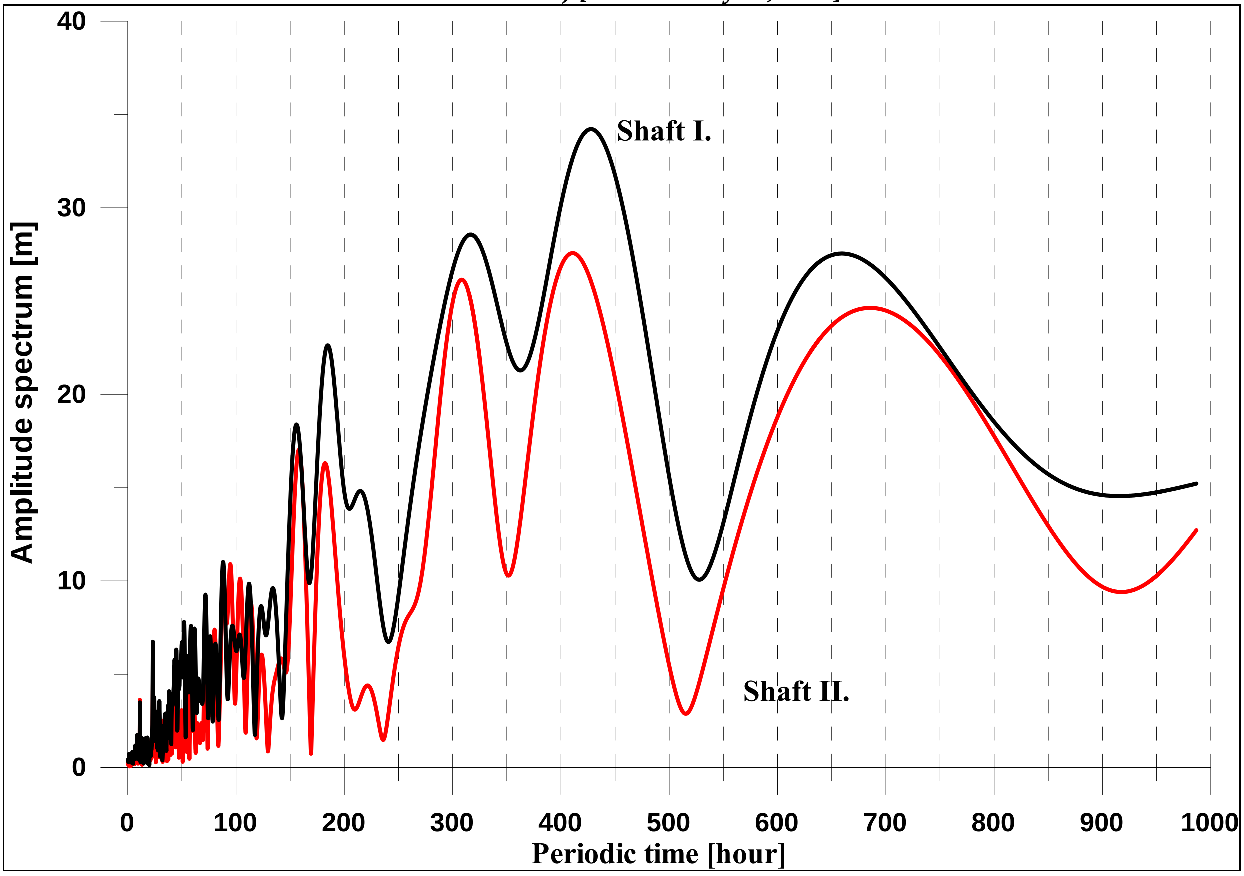


Fig. 3.4.63 Amplitude spectrums of measured water level data (Mátra region, Recsk) [Szucs and Nyari, 2005]

3.10.3.5. Determining the amount of effective precipitation

During my many years of research I concluded that rainfall at the Bükk will become „effective precipitation" (will cause significant karst water level and spring yield increase) only with the following conditions:

- at least 50 mm precipitation must fall, in form of rain, within one day time
- if the 50 mm precipitation falls not within one day, but within a few days time, the maximum pause (precipitation-free day) between precipitation days can be one day only

In 13 years we analyzed 39 „effective precipitation groups". The conclusion is that at the plateau of the Bükk (Nagy-fennsík Plateau, the highest point of the karst water relief) 1 mm „effective precipitation" causes 5.18 cm karst water level increase on the average ***[Lénárt, 2002, 2005a,b; Lénárt et al., 2002]***.

The average values carry no significance in the prognosis of the karst water levels. It is only informative data. But it gives me a chance to determine the monthly average values as shown on ***Figure 3.4.64***. It is clearly visible that the diagram has two „humps". The most significant specific karst water level increase is in March (when there is no considerable vegetation yet and the rain causes the remaining snow to melt) and in November (when the considerable vegetation is already gone and rain falls on large areas). The least effective area the precipitation in July, when the vegetation is considerable and the rain only falls in smaller areas ***(Figure 3.4.65)***.

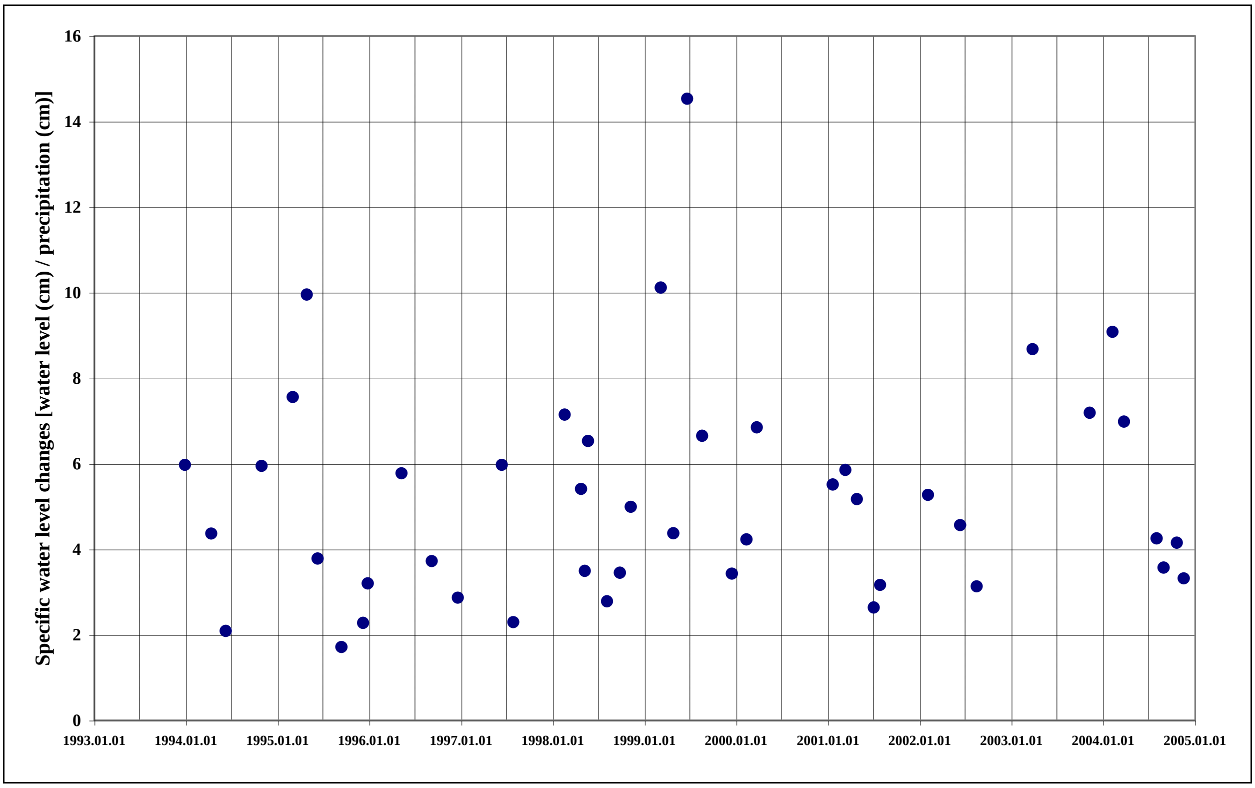
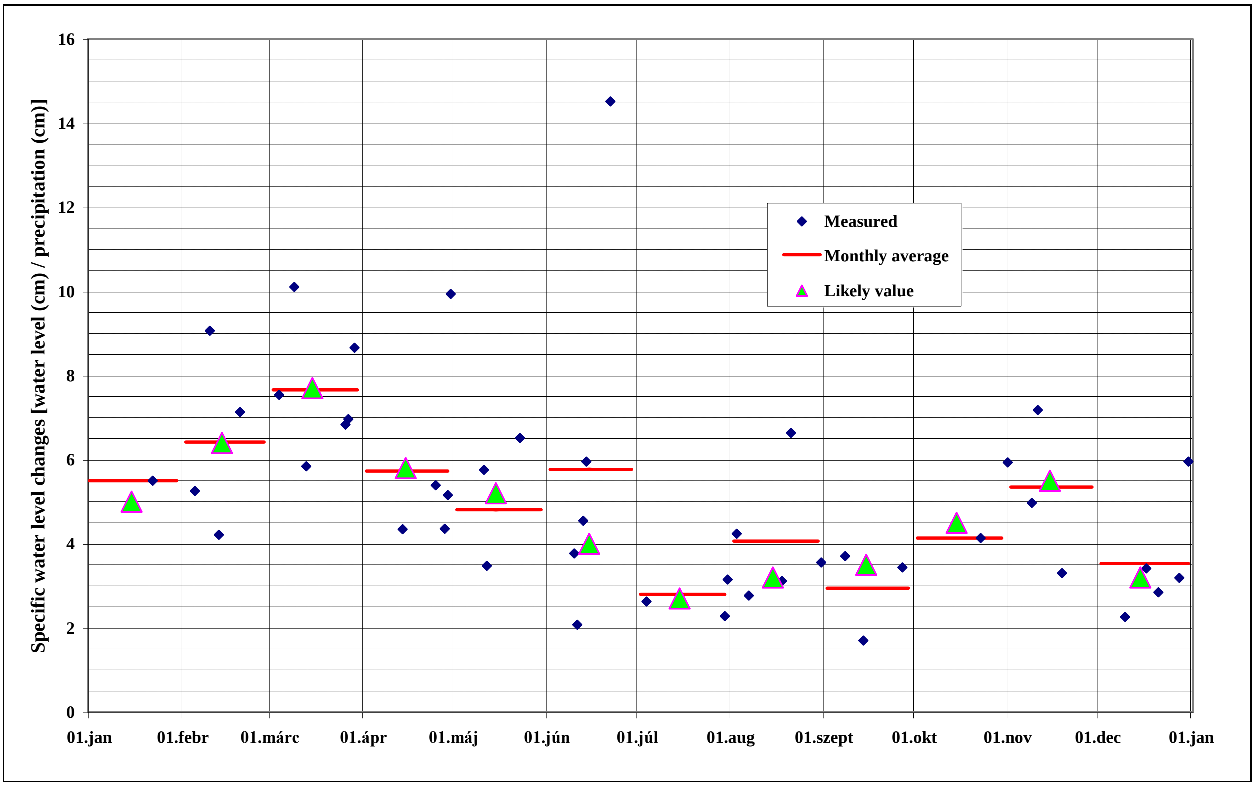


Fig. 3.4.64 Events of great specific water level changes in the same seasons, based on the daily averages in the Nv-17 karst water level monitoring well and the daily precipitation data recorded at Jávorkút in Bükk Mountains [Original, 2005]



3.4.65 Events of great specific water level changes in the same seasons, based on the daily averages in the Nv-17 karst water level monitoring well and the daily precipitation data recorded at Jávorkút in Bükk Mountains [Original, 2005]

3.10.4. Evaluation of karst waters by temperature on the study area

3.10.4.1. Categorization of waters by temperature

The rating of waters by their temperature can be done by many different methods ***[Juhász, 2002]***. Many scientists, such as ***OMBKE, 1907; Bányai, 1942; Slavlovský, 1992; Franko, 1994; Sásdi, in: Baross 1998; Benderev and Hristov, 2000*** thinks that the lowest limit of temperature of the thermal waters should be drawn at 15-25 °C. (In Hungary this limit in general is 30 °C; probably because this country is rich in thermal waters.) I suggest developing further these findings as follows (taking into consideration the other methods, too):

- <10°C: cold water
- 10-16 °C: cold-tepid water
- 16-25 °C: warm-tepid water
- 25-37 °C: warm water
- >37 °C: hot water

I suggest an important new aspect, that we should take the lowest values of the exploited water temperatures into consideration. (Of course this means that the categorization can be done only by depending on longer, more reliable data sets ***Lénárt and Sasvári, 2004; Lénárt et al., 2004b***.) My suggestion is that we compare these minimum values to the average air temperature of Hungary (10 °C), and to the average air temperature of the hydrological summer season of the entire country (16 °C). (These values should be modified to 9 and 15 °C in the Slovak Karst since this area is situated on the North compared to the Bükk and the Aggtelek Karst.)

The categorization of cold-tepid water and warm-tepid water has both technical, both research significance. In this last case, I would like to emphasize the increased presence of the water dwelling up from the deep.

I found own ***[Lénárt et al, 2004b; Lénárt, 2005b]*** and others' ***[Maucha, 1998; OVF-VITUKI, 2002; Tometz, 2004]*** data regarding waters with temperatures warmer than cold water – thermal water – ***(Figure 3.4.66)***. In details: proceeding from West to East, and South to North, there are 10 settlements with such data in the Bükk and its surroundings, 6 settlements on the Aggtelek Karst, and 2 on the Slovak Karst. I separated these areas and stated the present method of usage on ***Table 3.4.III***. (The list is not complete, further evaluation is necessary mostly In case of cold-tepid waters, for example certain springs of Bódvarákó and Martonyi. In ***Zat'ko [1969]*** the temperature of the Slovak springs had been shown by the height above sea level. ***Sásdi –[in Baross, 1998]*** – a had done the very same, applied to the springs of the Aggtelek Karst. In the first one the drilled wells of cold-tepid waters are not included. In the latter, one or two values are closer to the warm water category than to the warm-tepid category. It is probably because the chart is based on a one-time measurement, not done by temperature data row sessions. It is very difficult to show this connection In case of the Bükk. The warm and tepid-warm springs are situated between 127 and 205 m a.B.s.l., but it is not easy to determine the exact height of the discharge point in the boreholes containing warm water, because these wells are 150 m to 2.200 m deep. But it is clear that the temperature is increasing as we are getting deeper wells and as we are getting further away from the edge of the mountain ***[Aujeszky et al., 1974; Kleb and Scheuer, 1983]***.

The range and the size of the heat flow in the Carpathian Basin had been examined by many scientists. One of these is ***Korim 1994***, whose map I present here (this was done to modify the work of ***Čermák and Hurtig 1979***) ***(Figure 3.4.67)***, and a part of ***Dövényi 2003***'s map ***(Figure 3.4.68),*** which basically only contains the study area. (Other works could be listed as well, such as ***Slavkovský [1992]***, who used the figures of ***Franko et al. [1986]***, but these works did not reach over the political boundaries. One example of these is ***Figure 2.1.18***.)

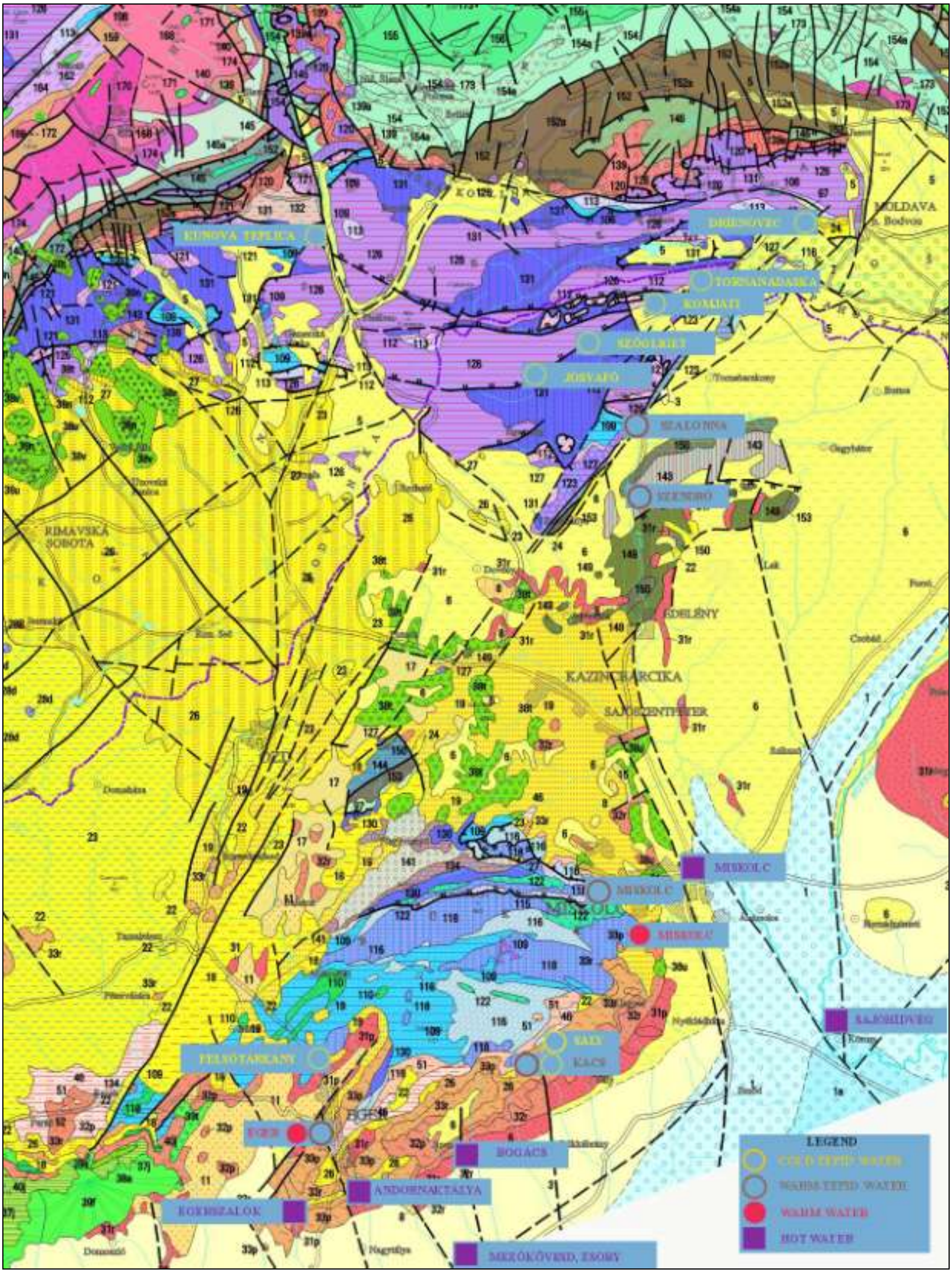


Fig. 3.4.66 Thermal water locations in the study area [Orig., 2004, Base map: Lexa et al., 2000; See Fig. 2.1.8]

Table 3.4.III.

Thermal water locations in the study area

Settlement	Type of thermal water	Usage
Egerszalók	hot	Bath, developing medicine, ecological water, spectacle
Eger	warm-tepid; warm	Drinking water, bath, medicine, spectacle
Felsőtárkány	cold-tepid	Communal
Andornaktálya	hot	Bath
Mezőkövesd	hot	Bath, medicine
Bogács	hot	Bath
(Recsk)	(hot)	(Mining dewatering; dewatering process ended at 1999)
Kács	cold-tepid; warm-tepid	Drinking water, ecological water, spectacle
Sály	cold-tepid	Drinking water, ecological water, spectacle
Miskolc	warm-tepid; warm; hot	Drinking water, bath, medicine, spectacle, hot water system, heating of business buildings, bottled water
Sajóhídvég	hot	Agricultural usage
Szendrő	warm-tepid	Ecological water, spectacle
Szalonna	warm-tepid	Drinking water
Jósvafő	cold-tepid	Ecological water, spectacle
Szögliget	cold-tepid	Ecological water, spectacle
Komjáti	cold-tepid	Ecological water, spectacle, drinking water
Tornanádaska	cold-tepid	Ecological water, spectacle
Kunová Teplica	cold-tepid	Drinking water
Drienovec	cold-tepid	Ecological water, spectacle, drinking water

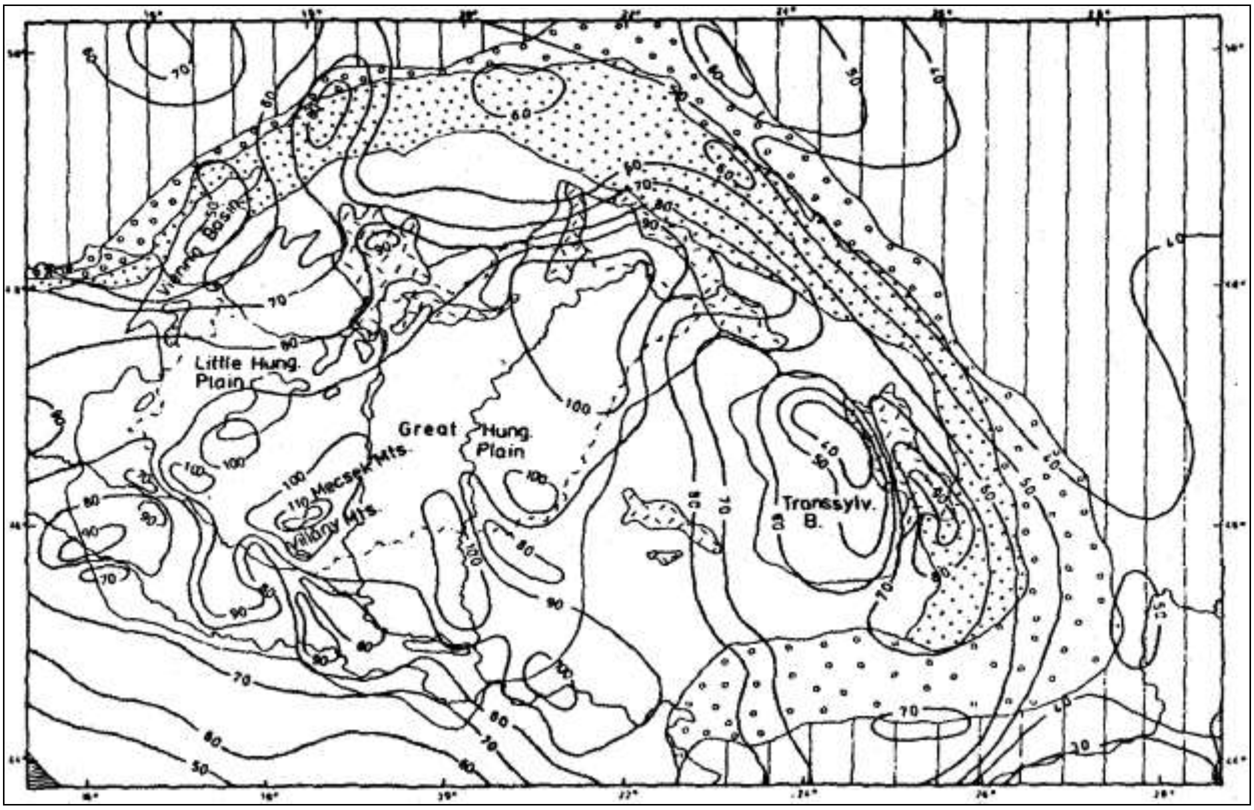


Fig. 3.4.67 Isolines of heat flow in mW/m^2 unit for the Carpatho-Pannonian area
[Korim, 1994, modified from Čermák and Hurtig, 1979]

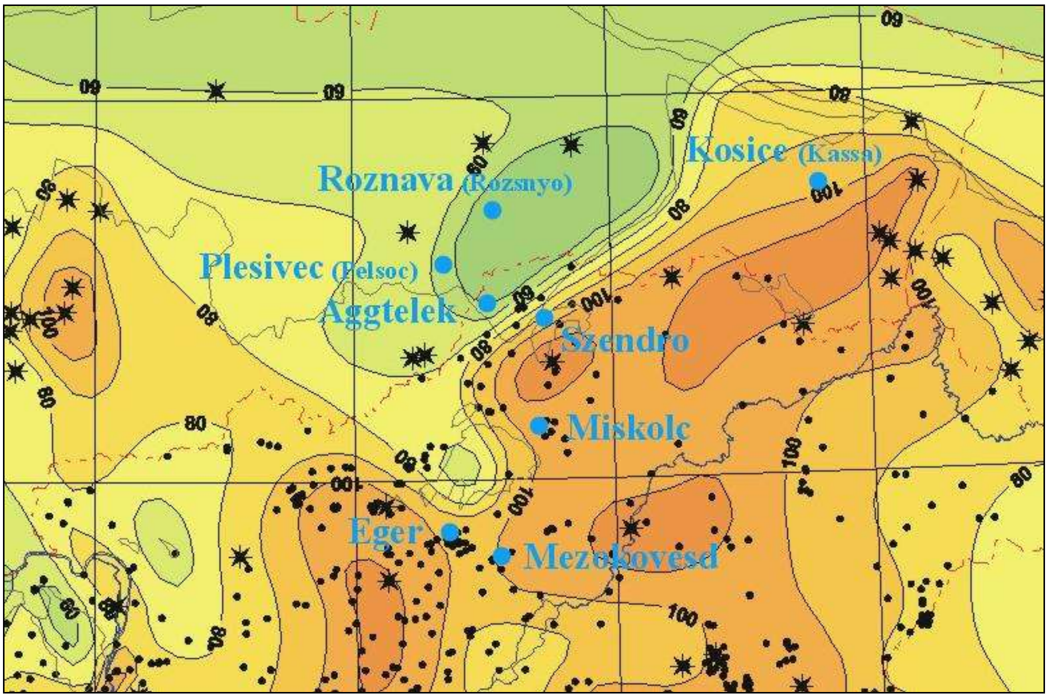


Fig. 3.4.68 Isolines of heat flow in mW/m^2 unit for the study area [Dövényi, 2003]

The geothermic energy is considered to be a very important natural resource in Hungary. Its exploitation is mostly significant in the tourism which is based on thermal water (in our case, karstic thermal water). (The karstic thermal water is represented separately from the rest in the mark able water bodies within the frames of WFD, see ***Figure 2.1.18***.)

The geothermic energy is taken into account is Slovakia, too. Let me mention the work of ***Kuzevičova et al. [1999]; Fendek [2000]*** as an example, in which the most hopeful area in this sense is the Northeastern part of our study area.

The possibility of the development of the thermal karst in shown on ***Figure 3.4.69*** based on the work of ***Liebe [2003]***. I will show the scheme of the development of the thermal spring on ***Figure 3.4.70***, made by ***Hertelendi et al., [1994]***.

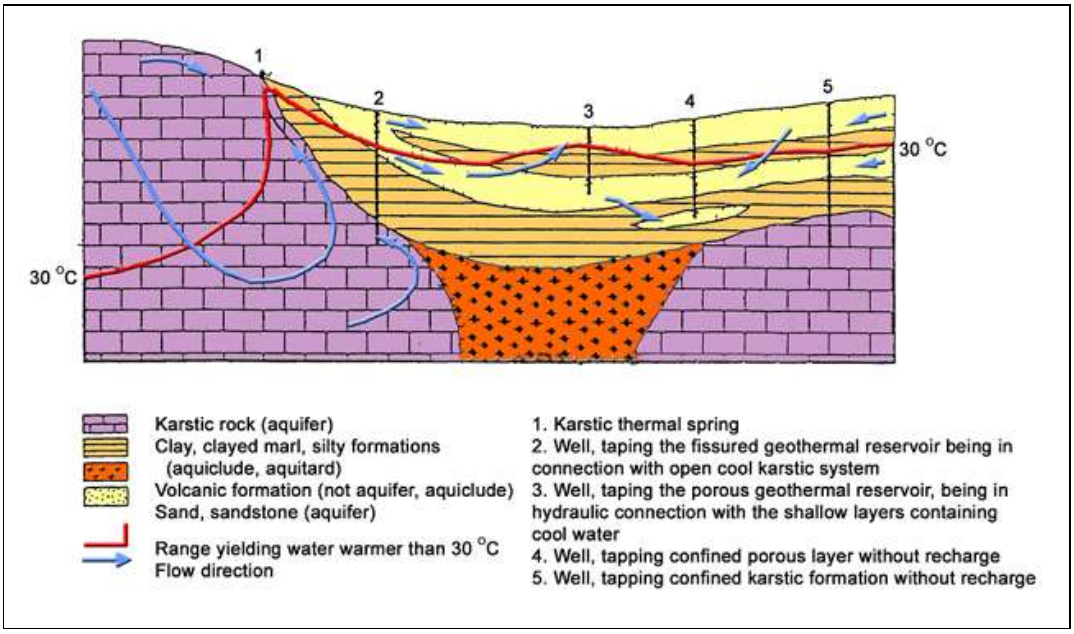


Fig. 3.4.69 The possibility of the development of the thermal karst [Liebe (editor), 2003]

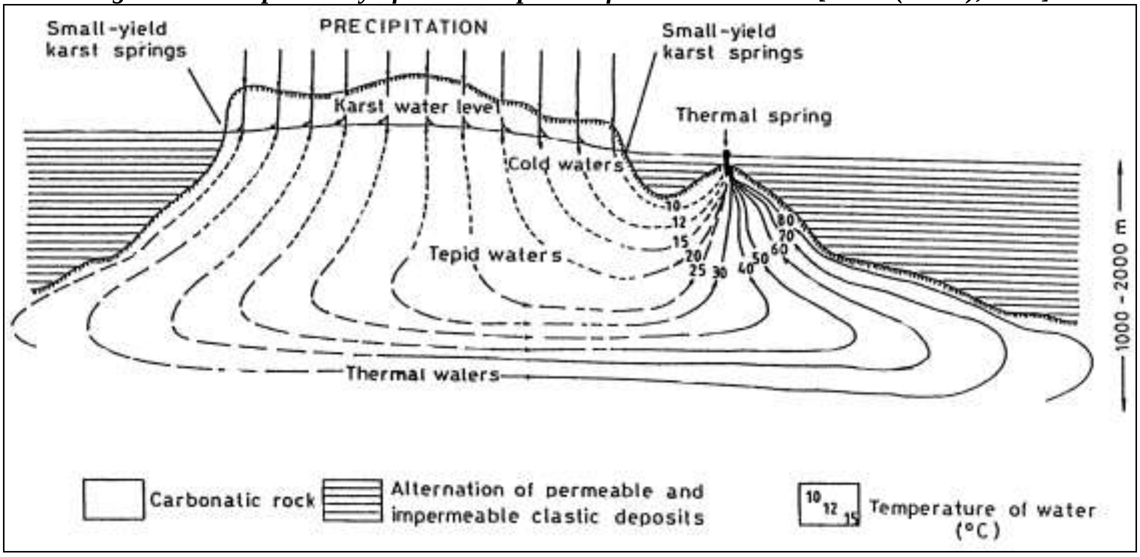


Fig. 3.4.70 Theoretical hydrological profile of the thermal karstic system [Hertelendi et al, 1994]

The temperature of the emerging water changes in all three areas depending on the level of emerging. The temperature of the springs never goes over 32 °C. ***Figures 3.4.71 and 3.4.72*** show the locations of the exploited thermal karst water through wells which temperature is 29-92 °C. (The water enters the wells 150-2.200 m under the surface.) The Bükk has cold-tepid, warm-tepid warm and thermal waters, the Aggtelek Karst has only cold-tepid and warm-tepid waters, and finally the Slovak Karst has only cold-tepid water. The difference is based upon the following:

In our study area the absolute height of the karst water level is decreasing toward the North, meaning that the karst water gets into the deep karst on lower pressure. The other significant difference is that on the South (in the Southern surroundings of the Bükk) a very thick layer of sediment blocks the water from its natural course of coming to the surface, and this sediment layer missing on the North, or at least it is much thinner.

3.10.4.2. The thermal karst water system of the Bükk

The evaluation of the Bükk and its surroundings has started long ago and is far from being finished ***[Sárváry, 1992a,b, 1997; Izápy and Sárváry, 1992; Izápy and Maucha, 2002; Smaragd, 2003]***. The work of ***Izápy and Sárváry [1992]*** about Eger and surroundings ***(Figure 3.4.71)***, using the 1974 work of ***Szlabóczky, Görög [2003] (Figure 3.4.72)*** shows the connection between the open and covered karst of Miskolc surroundings.

The relationship of the tightly connected cold and thermal karst – practically the open and covered karst ***[Böcker and Vecsernyés, 1983; Bernáth et al., 1992a,b; Sárváry, 1992a,b; Hetelendi et al., 1994, 1995; Lénárt, 1995a; Somody and Lénárt 2002, 2004; Smaragd 2003; Tometz 2004; Lénárt et al. 2004b,c]*** is clearly noted at ***Simonffy [2003a,b] (Figure 2.1.18)***, who is delineating the (karstic) water bodies in Hungary according to the Water Framework Directive (WFD).

This thermal karstic water resource is being directly tapped at Miskolc, Kács, Bogács, Mezőkövesd, Eger, Egerszalók and Sajóhídvég through springs and deep-drilled wells.

Springs are known with temperature of 15 °C around Drienovec on the Slovak Karst ***[Tometz, 2004]***.

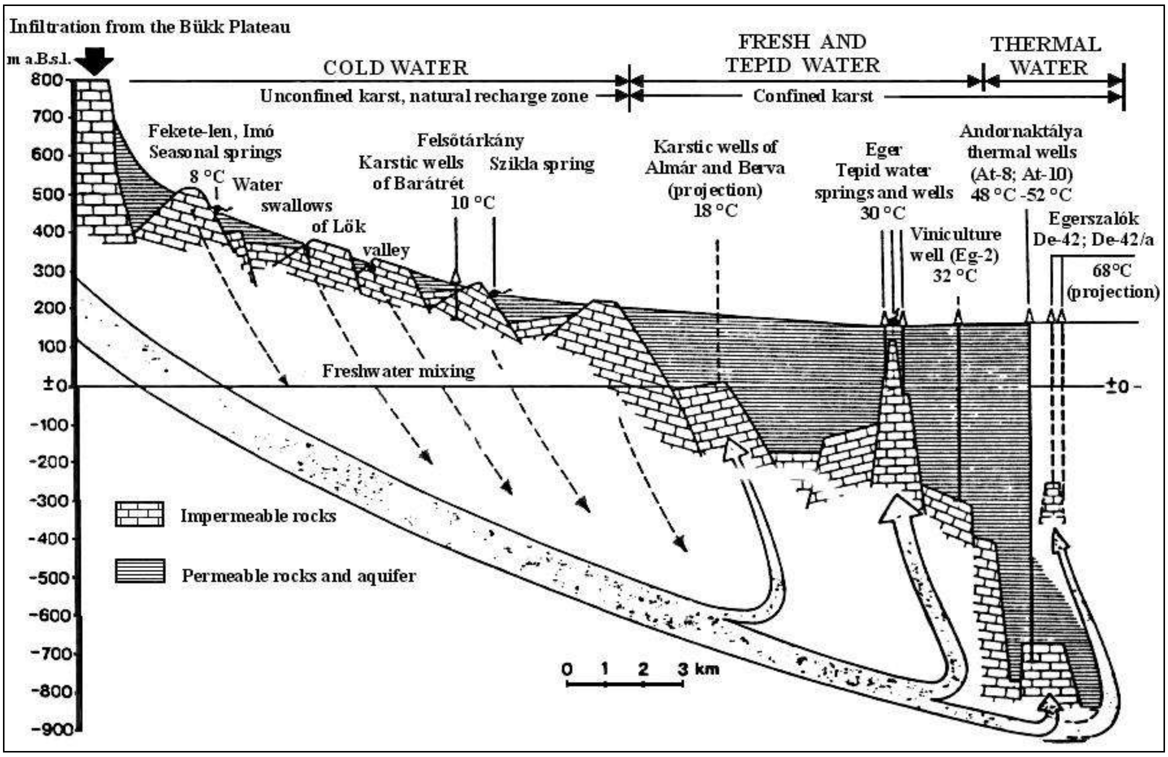


Fig. 3.4.71 The sketch of thermal karst system in Eger area
[Lénárt, 2005; based on Izápy and Sárváry, 1992, based on the findings of Aujeszky et al., 1974]

The connection between the thermal wells of Miskolc and the Termál-spring of Miskolctapolca had been shown as early as the middle of the 1960's ***[Kerekes and Szpiriev, 1964; Kessler, 1964; Kessler and Ihring, 1964]***. Since then the data collected are proving this connection, but there are opposing opinions, too. (Among professional circles this opinion is usually not taken seriously, but due to unclear legal perceptions sometimes this opposing opinion is being presented very strongly.)

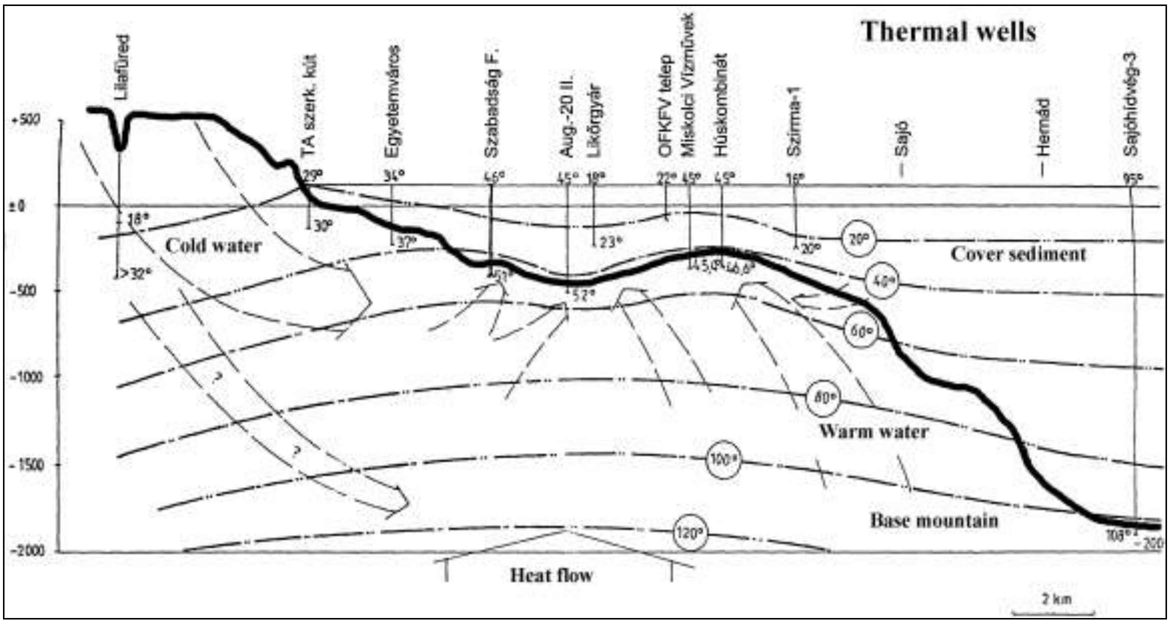


Fig. 3.4.72 The sketch of thermal karst system in Miskolc area [Based on the findings of Szlabóczky, 1974, completed with new data by Görög, 2003]

The evaluations of the University of Miskolc between 1991 and 1995 also proved the clear and tight relationship ***[Bernáth et al., 1992a,b; Lénárt, 1995a]***. This statement was confirmed by the evaluations under continuous wellhead pressure and water temperature ***[Lénárt 2005b]*** in 2003.

In the following figures I present the very close connection between the cold and warm karst water. All of these illustrations show very well the tight connection between these two kinds of water in the Bükk Mountains.

I already mentioned the measurement session that took place between 1991 and 1995. Out of its results I want to show on ***Figure 3.4.73***, how I portrayed the cold water data that was taken continuously and the warm water data that was taken in every 2-5 days in a single system.

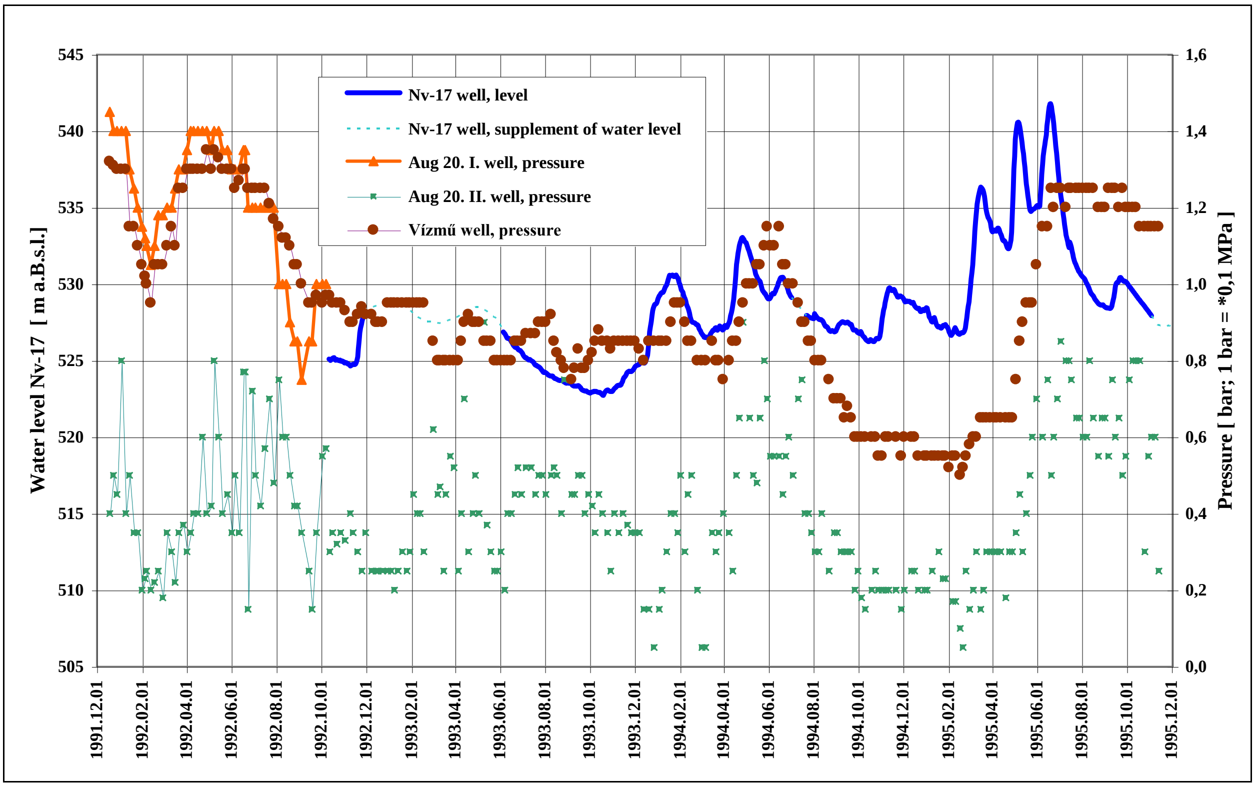


Fig. 3.4.73 The changes in the cold karst water level of the Bükk and the changes in the pressure level of the thermal karst water in the Bükk surroundings 1991-1995 [Original, 2004]

The measurement session that was interrupted in 1995 was started again in year 2002, when the measurement points were equipped with measurement tools collecting data continuously. The data collected between year 2002 and 2005 are shown on ***Figure 3.4.74***. The tight connection is very clearly visible.

Let me take the data of this relationship for the year 2004 and show it on ***Figure 3.4.75***. The cyclic movements of the pressure of the warm karst water and its dependence on the cold karst water level can be followed very well.

Let me present the results of the continuous measurements of karst water level. The session had been started over 10 years ago. Despite some missing data the connection is clearly visible ***(Figure 3.4.76)***.

Out of this relationship let me take the data for the year 2004 and show it on ***Figure 3.4.77***. The cyclic movements of the warm karst water level and its dependence from the cold karst water level can be followed very well.

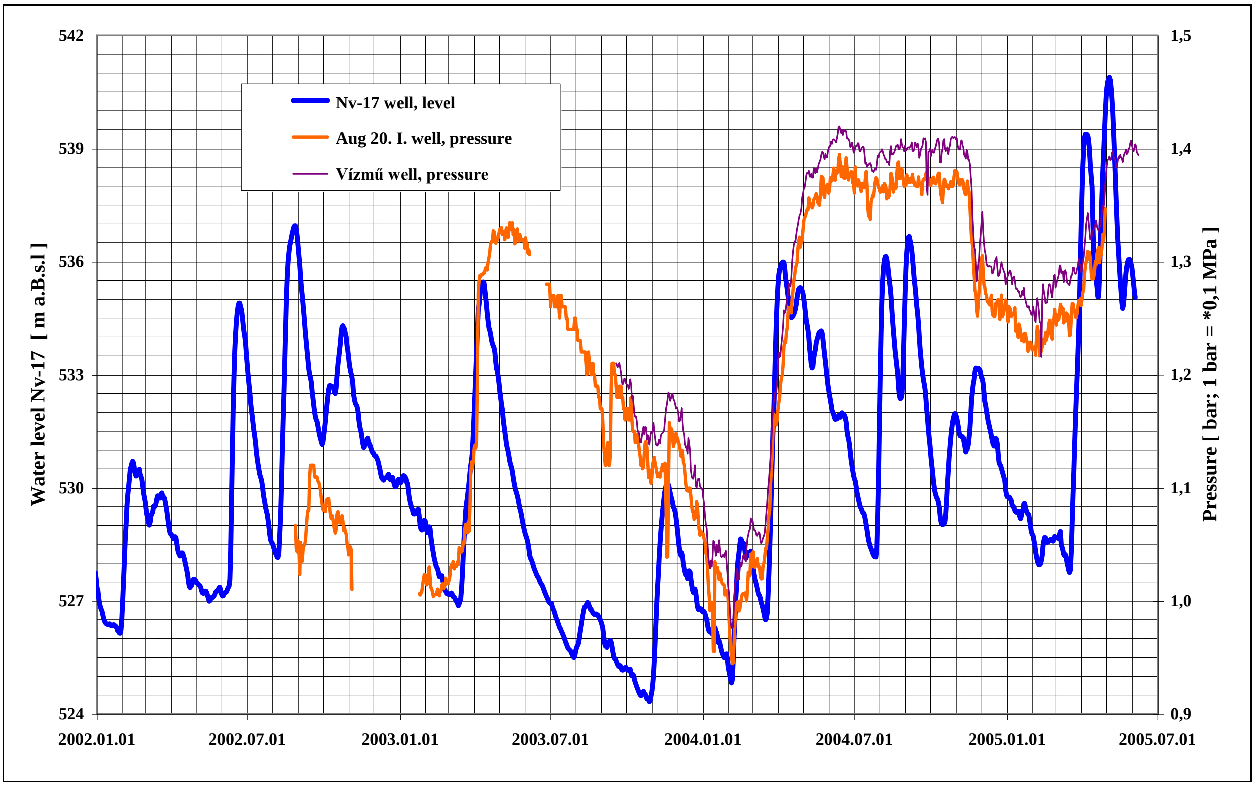


Fig. 3.4.74 The changes in the cold karst water level of the Bükk and the changes in the pressure level of the thermal karst water in the Bükk surroundings 2002-2005 [Original, 2005]

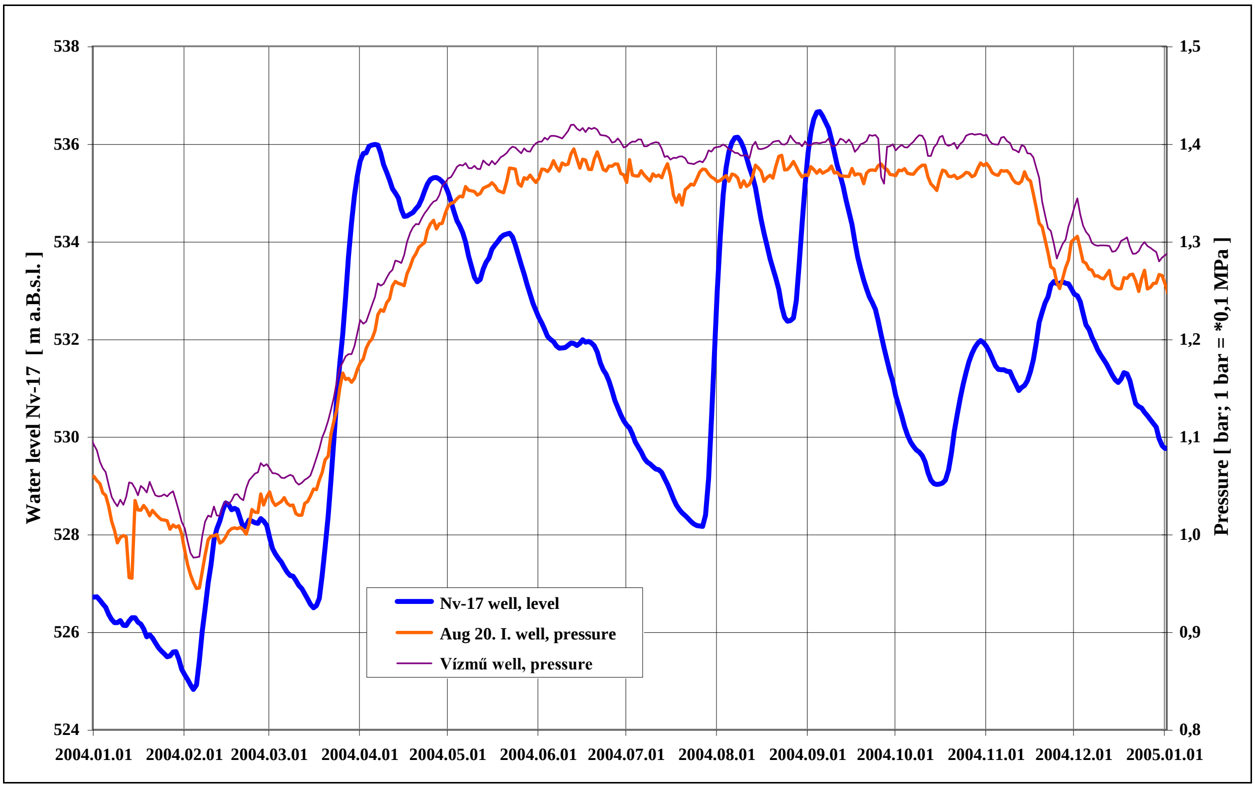


Fig. 3.4.75 The changes in the cold karst water level of the Bükk and the changes in the pressure level of the thermal karst water in the Bükk surroundings 2004 [Original, 2005]

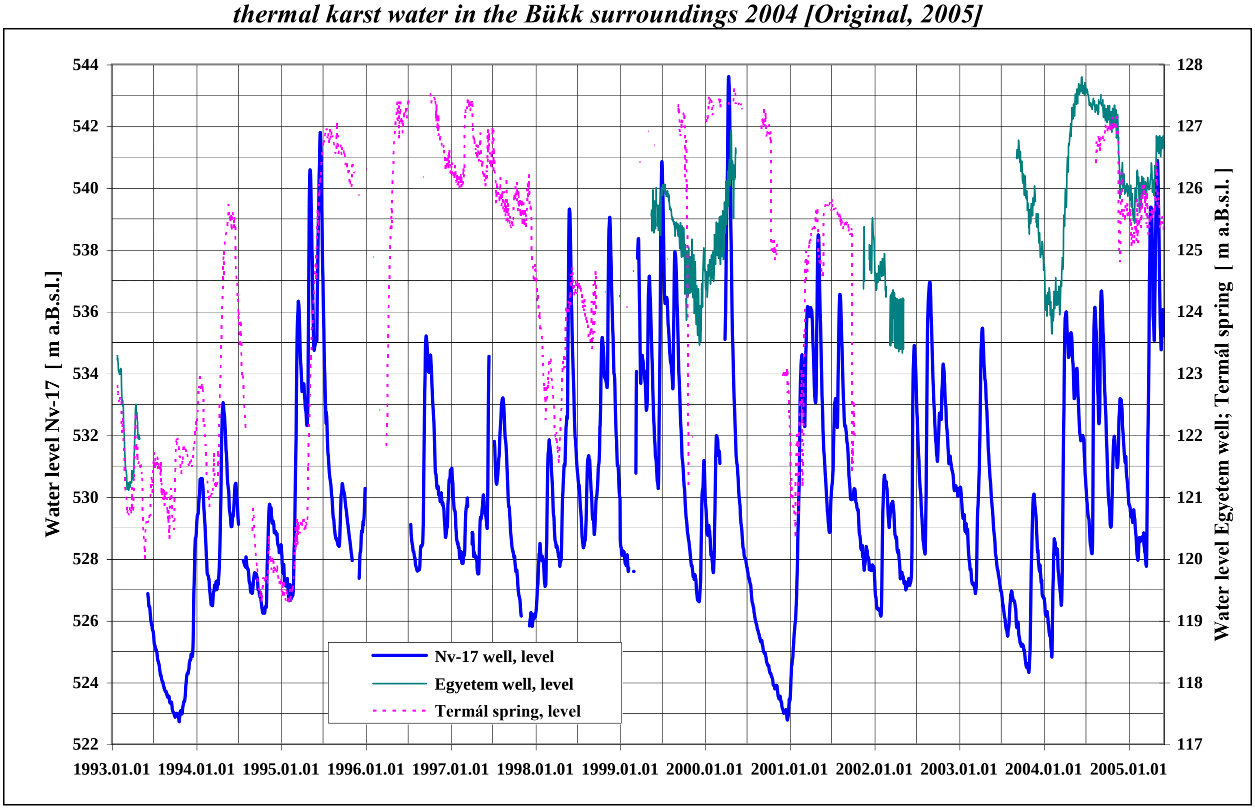


Fig. 3.4.76 The changes in the cold karst water level of the Bükk and the changes in the water level of the thermal karst water in the Bükk surroundings 1993-2005 [Original, 2005]

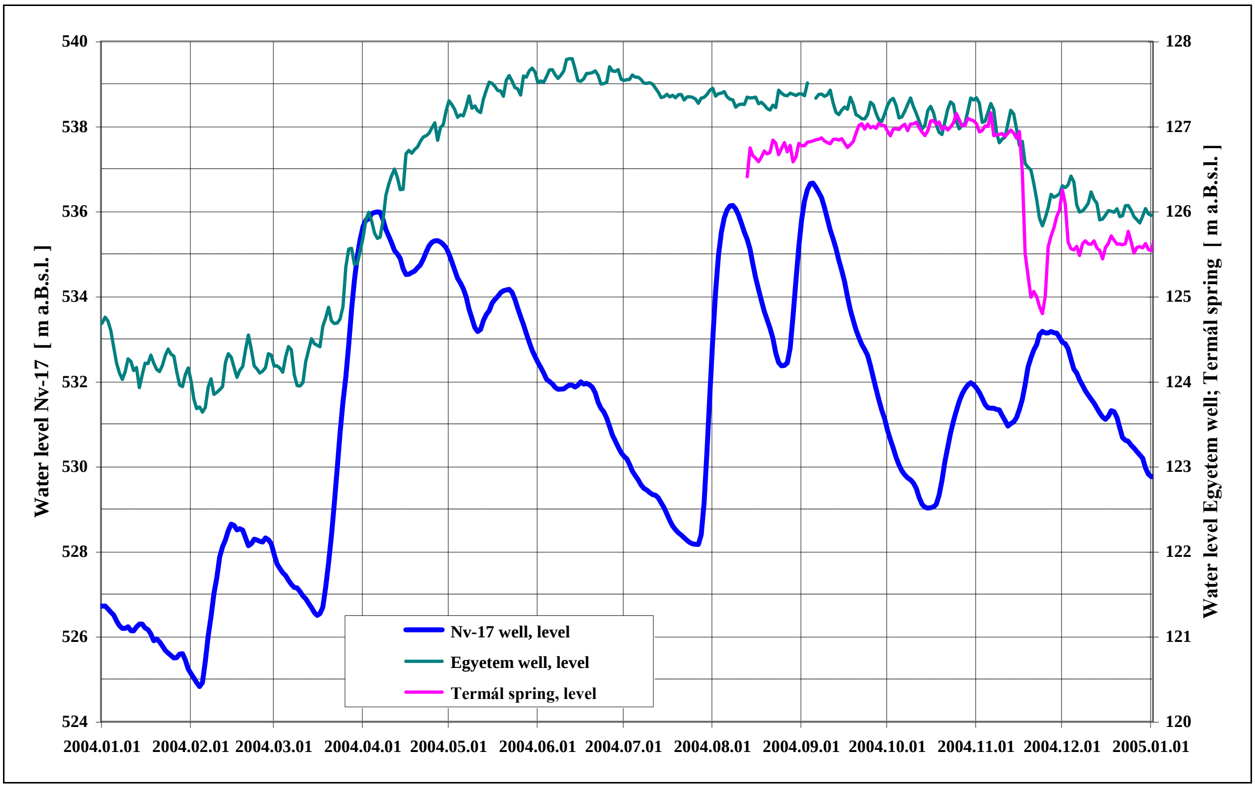


Fig. 3.4.77 The changes in the cold karst water level of the Bükk and the changes in the water level of the thermal karst water in the Bükk surroundings 2004 [Original, 2005]

Figure 3.4.78 shows the water level changes of the warm-tepid Tükör spring of Kács. The cyclic movements mentioned above are present here as well.

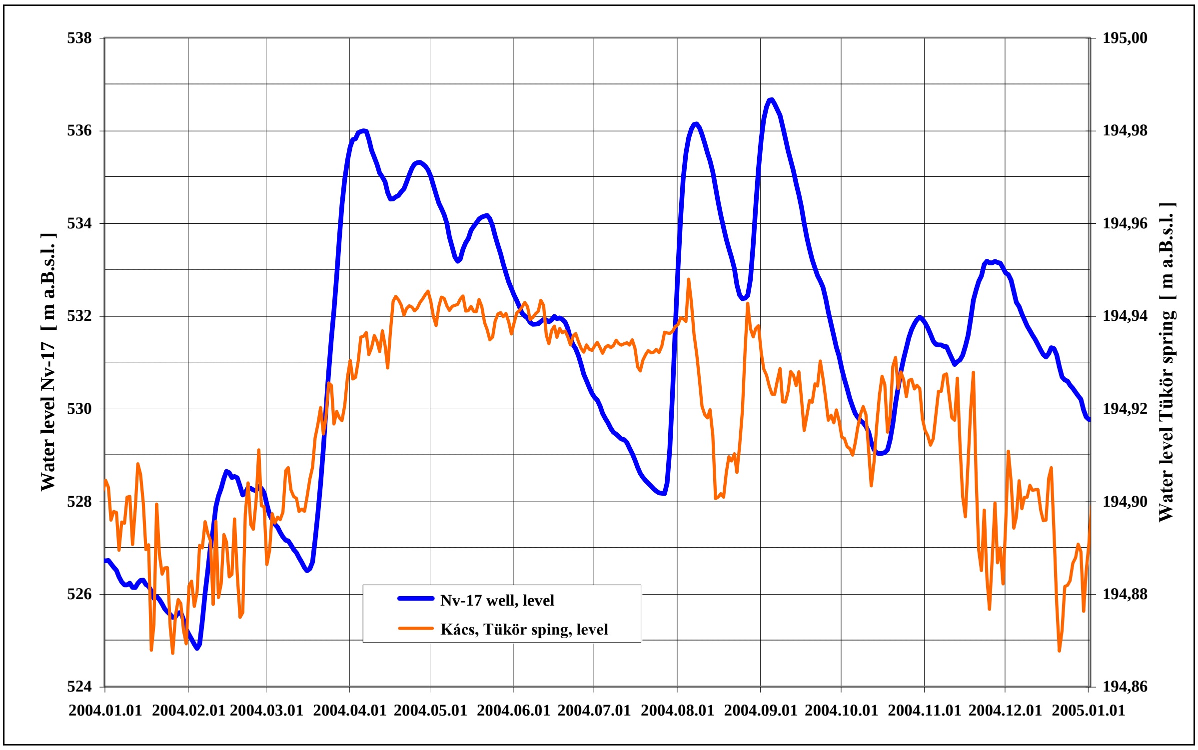


Fig. 3.4.78 The changes in the cold karst water level of the Bükk and the changes in the water level of the luke-warm karst water in the Bükk surroundings 2004 [Original, 2005]

Figures 3.4.75 and 3.4.77-3.4.78 tell us that the level and the pressure of the thermal karst water had changed suddenly and considerably at the end of November, 2004. The last diagrams will show the reason for such a rapid change.

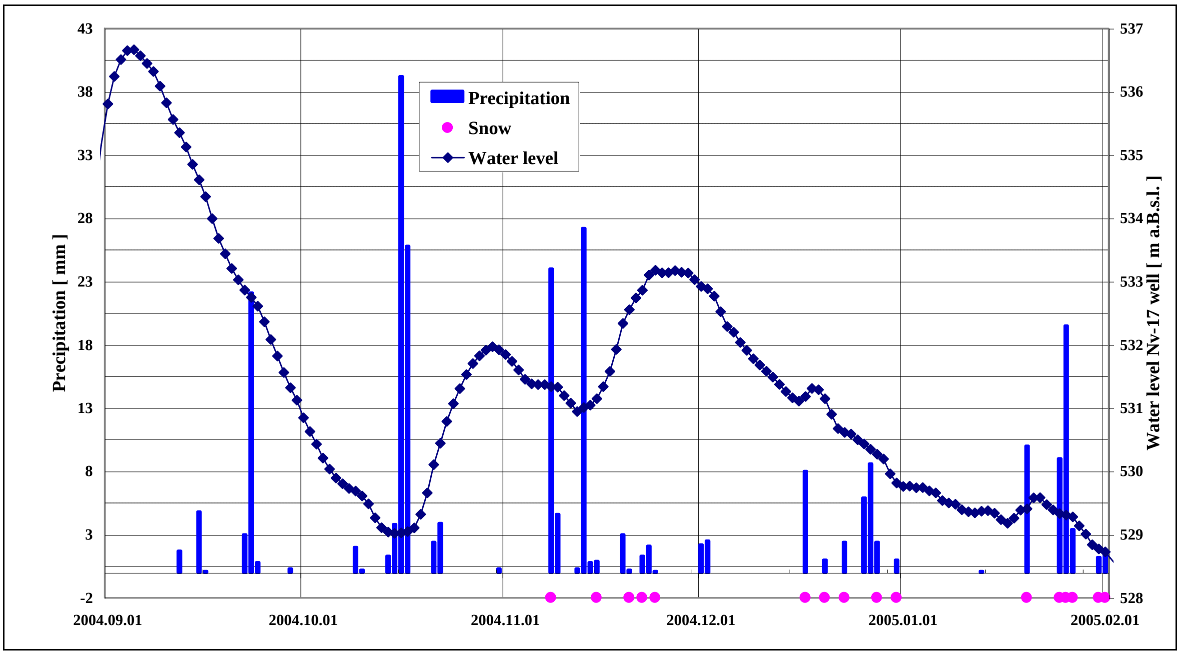


Fig. 3.4.79 The daily precipitation and changes in the cold karst water level of the Bükk at "Nv-17" monitoring well [Original, 2005]

Figure 3.4.79 introduces the daily precipitation and the changes of the karst water level in the Nv-17 monitoring well. There was a great amount of precipitation in the middle of November, in unusually cold weather; both rain and snow. The effect of this can be seen in the water level curve. (The water production values were not out of range of the usual, so the changes present on ***Figures 3.4.75 and 3.4.77-3.4.78*** are probably originated only from the water temperature and changes in the karst water level.)

The water temperature changes of 2 very significant cold springs are shown on ***Figures 3.4.80-3.4.81.*** The drop in temperature is very intensive.

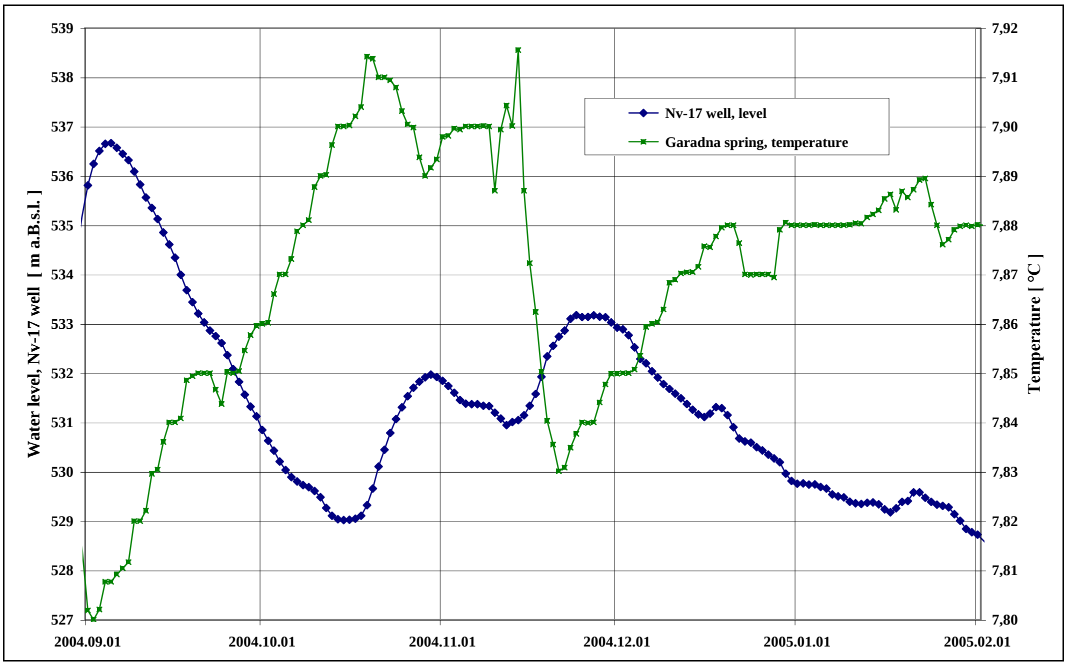


Fig. 3.4.80 The changes in the cold karst water level of the "Nv-17" monitoring well and the changes in the temperature of the cold karst water in the "Garadna" spring [Original, 2005]

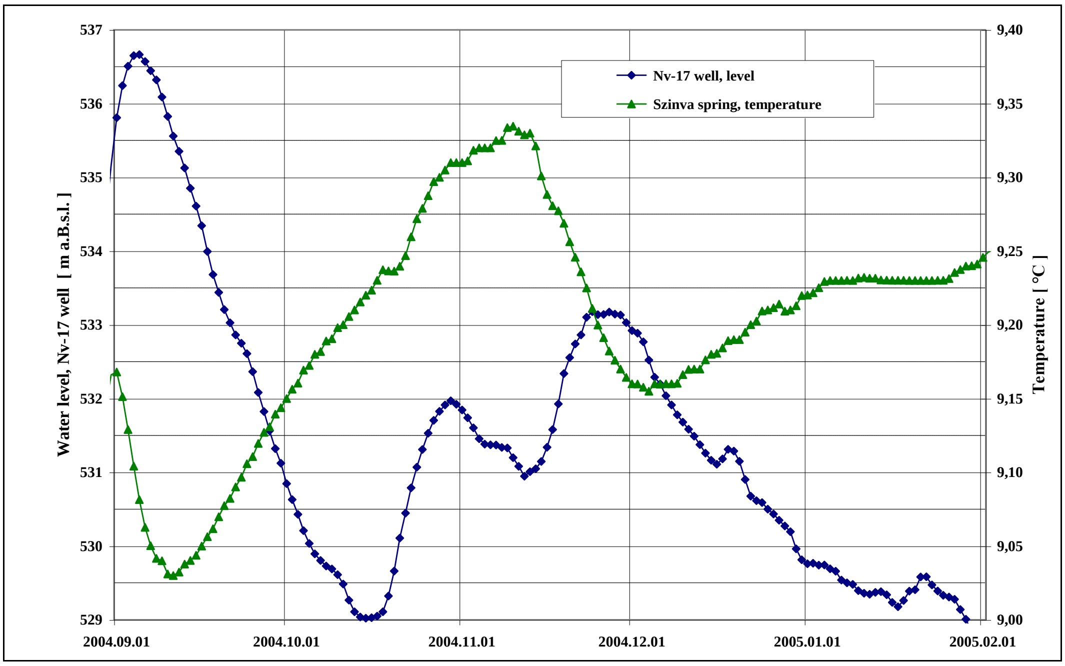


Fig. 3.4.81 The changes in the cold karst water level of the "Nv-17" monitoring well and the changes in the temperature of the cold karst water in the" Szinva" spring [Original, 2005]

The water temperature change of a warm-tepid spring (at mountain edge) is shown on ***Figures 3.4.82***. The drop in temperature is very intensive. It comes from the mixing of the up surging warm water and the chilled (cold) water. This results in a cooler temperature of the spring water itself.

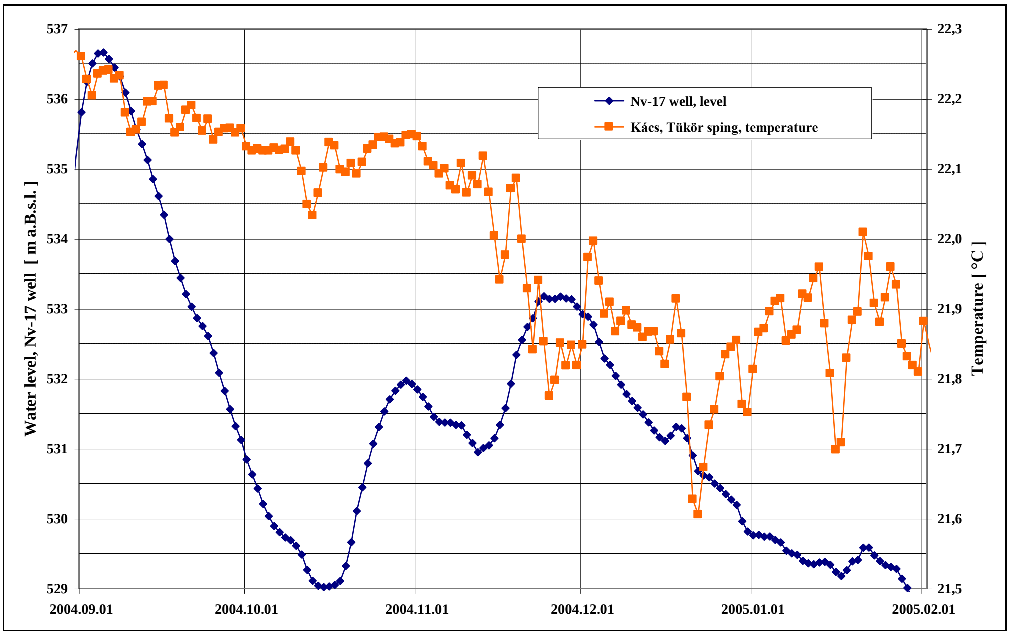


Fig. 3.4.82 The changes in the cold karst water level of the "Nv-17" monitoring well and the changes in the temperature of the warm-luke-warm karst water in the "Tükör" spring [Original, 2005]

Of all the studied places the "Thermal" spring (Miskolctapolca) shows most clearly the changes in temperature ***(Figure 3.4.83)***. Due to the decrease in the level and pressure of the cold water in September and October, the warm water dominated over the cold in the spring. But the cold precipitation of November month showed up as mixed water in the spring and cooled off the water temperature.

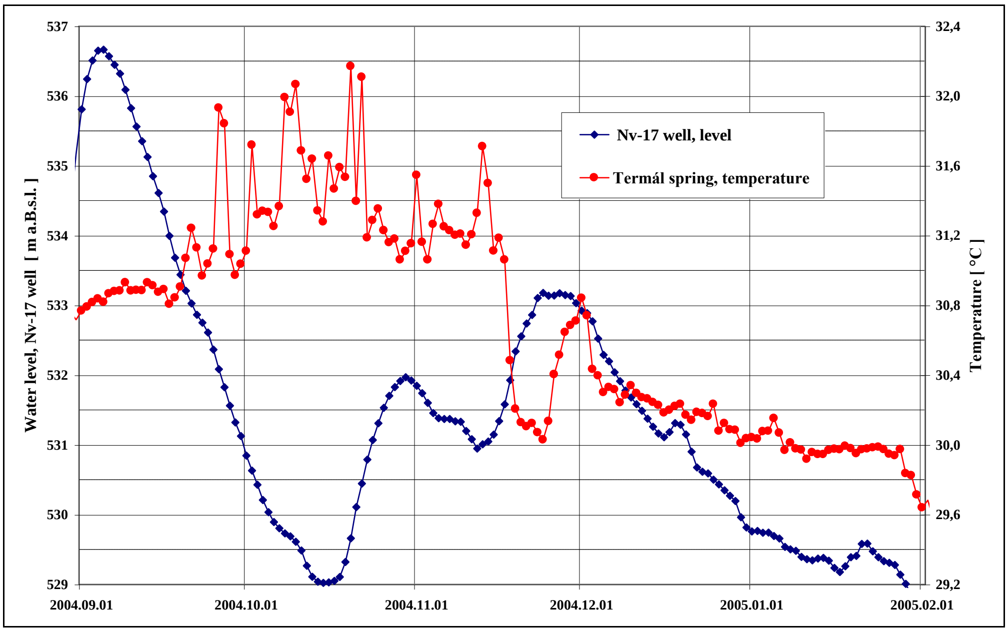


Fig. 3.4.83 The changes in the cold karst water level of the "Nv-17" monitoring well and the changes in the temperature of the luke-warm-warm karst water in the "Termál" spring [Original, 2005]

This change doesn't show up in the temperature of the thermal wells because in this short period of time the cooled – cold karst water couldn't get to the wells ***(Figures 3.4.84-3.4.85)***. (That minimal change that is visible is probably due to surface weather temperature change.)

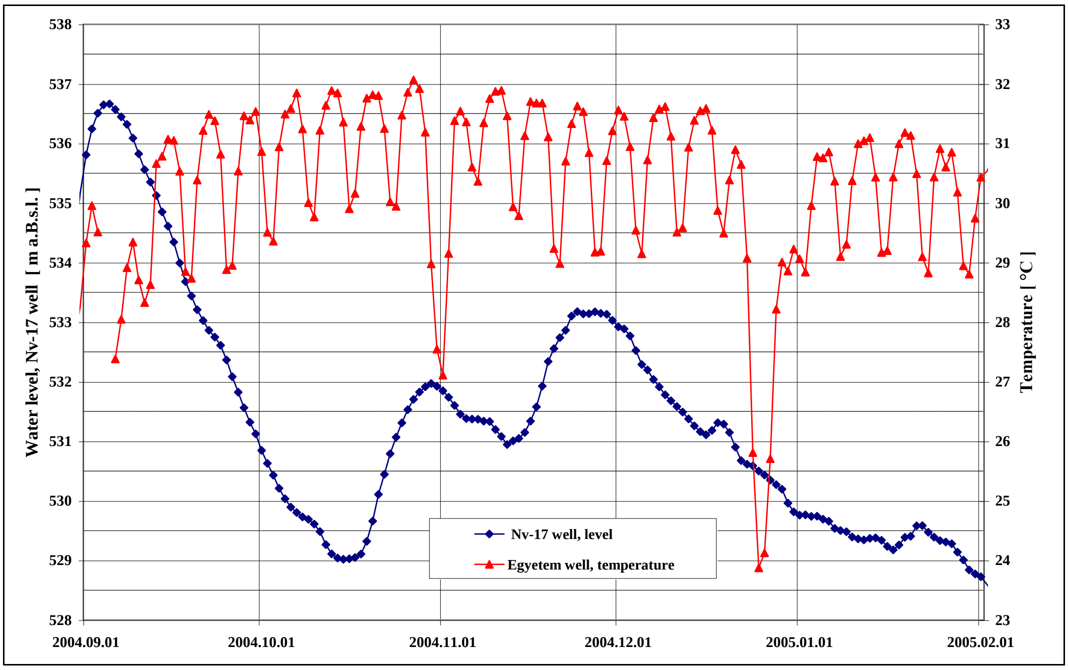


Fig. 3.4.84 The changes in the cold karst water level of the "Nv-17" monitoring well and the changes in the temperature of the warm karst water in the well "Egyetem" [Original, 2005]

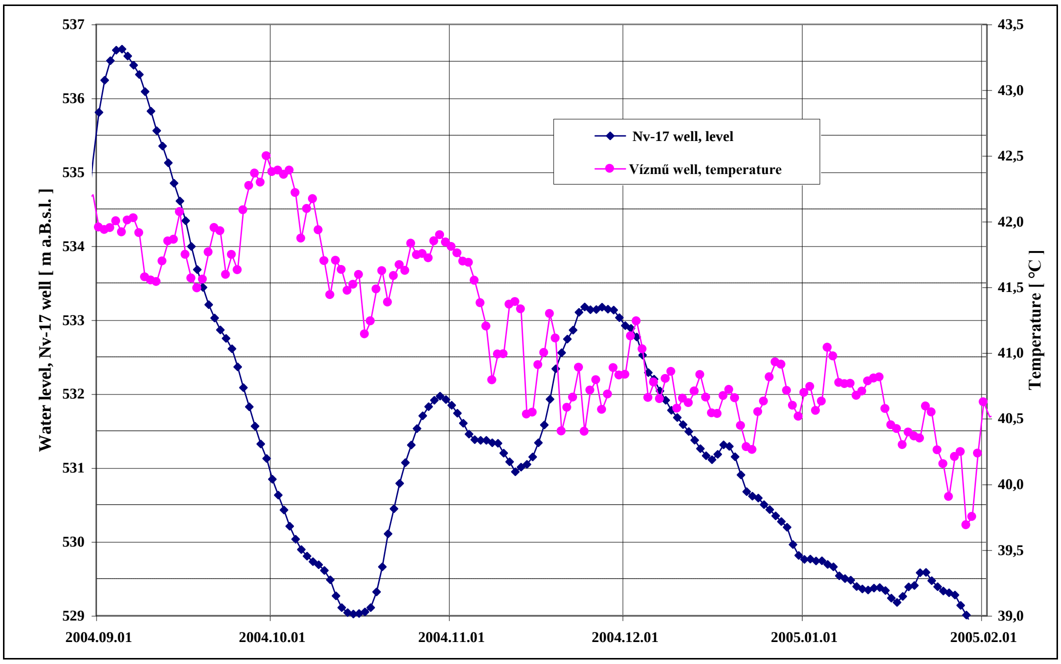


Fig. 3.4.85 The changes in the cold karst water level of the "Nv-17" monitoring well and the changes in the temperature of the warm karst water in the well "Vízmű" [Original, 2005]

Many authors shares the opinion that there is a relationship between the thermal water exploitation establishments located further away from each other and that the thermal water system of the Bükk is overproduced ***[Izápy and Sárváry 1992, Lorberer-Szentes et al. 1977, Lorberer 2002a,b, 2003]***.

I already listed the values of the water production and exploitation of the Bükk on ***Figures 3.4.15-3.4.18***.

In order to protect the thermal karst water resources and the existing users the delineation of the well-head protection zones of certain parts of the Bükk has started. The first one was completed at Bogács in 2003. Presently the delineation of the Egerszalók De-42 and De-42/a well-head protection zones is in the phase of authority delineation. (The evaluation of the thermal karst protective zone can be expected shortly in Miskolc, according to the present state of law and economy. It is necessary despite the delineation of the water company springs of Miskolc protective zone in 1989, according to the standards back then. This delineation separately marks out the covered (under pressure) thermal karst protective zone. The modern drawing of the protective zone is very important because of the new research and production results and the changes in the legal-economical environment.)

Following the previous chapters, the relationship between the cold and warm karst water is clear. The cold karst water on pressure level of the Bükk at 523-544 m a.B.s.l. controls the outflow of the cold-tepid and warm-tepid springs at 120-205 m a.B.s.l., and drainage depths of the warm waters and hot waters at –200- -2 000 m a.B.s.l.. The Bükk forms a connected cold-warm karst water system, with separable partial aquifers at certain level of the evaluations.

According to the summarized opinions the karst water exploitation of the Bükk has reached such a level nowadays that any additional exploitation would endanger the entire system. It means that it is important to consider the exploitations of existing producers when thinking of further developments. Also, new producers should only enter the exploitation if proven beyond doubt that the new exploitation will not cause impermissible decrease in the temperature of the water, water level, pressure level or yield.

There are signs of thermal water on the study area both on the surface (Tapolca-Teplica names, tepid and warm springs), both in the caves (Miskolctapolca Várhegy caves, Esztramos, Teplice-cave) ***[Pávai-Vajna, 1930, Dénes, 1965, 1983]***. Due to this the delineation of the thermal karstic water bodies on all three areas is reasonable. (This applies to the Slovak Karst, too, despite their present opposing official opinion.)

3.11. The Radon content of the karst waters

The University of Miskolc and the Institute of Nuclear Research of the Hungarian Academy of Sciences (Atomki, Debrecen) had performed Radon tracing measurements in the frame of a scientific collaboration "between" 1983 to 2001, partly out of professional interest. (See chapter 2.2.4. also.) In this paper I would like to talk about parts of this measurement session, namely the ones performed in springs of the Bükk (1991-1992), in the springs and caves of the Bükk (1991-1998) and in the apartments of Miskolc (1993-2001). (In the first case the Central Geological Bureau, in the second the Ministry of Education, in the third the Municipality of Miskolc was the principal.) I had measured the Radon content of the waters of Bükk in

- laboratories (partly)
- caves (mainly)
- springs
- deep-drilled wells
- water (toilet) tanks of apartments

Two of my main statements must be underlined:

- the Radon content of the water of Bükk heavily depends on the geological features of the discharging point,

- the Radon content of the karst water of the Bükk is not harmful

The alpha-radiation in our environment mostly originates from the decomposition of Radon. Radon is being carried by the moving water. In closed spaces (for example in caves) it might increase significantly. (I will only mention my measurements that were done in water. My evaluations in the air spaces of caves proved that neither the speleologists, nor the participants of the cave therapies are not subjected to unhealthy radiation dose.)

The amount of Radon in the waters moving through the rock depends on the kind of rocks the water moves through. The average amount of Radon concentration is between 0,5-12 kBq/m^3 at certain sites of the Bükk ***(Figure 2.2.3)***.

I already presented a map of the cave which is the main scene of the in-cave measurements - the Létrási-Vizes Cave, on ***Figure 2.2.2***. (During the measurement session in the cave I tried to collect a very complex data series: measurements were taken systematically in every month between 1983 and 1998; I measured the temperature of the air and the water, the drip yields, the water level of the in-cave lake. I also kept changing the Radon detectors, and counted the number and species of bats and their exact location. There was no separation between work and "cave visiting only" for us.)

Figures 3.5.1-3.5.2 show pictures of in-cave Radon detector changing trips.

Fig. 3.5.1 Radon detector changing in the Létrási-Vizes Cave. Left: the author, right: Somogyi György, the most significant person of the Hungarian Radon research [Unknown photographer, 1983]

Fig. 3.5.2 The team of the 100th Radon detector changing trip to the Létrási-Vizes Cave [Photo: Borka, 1991]

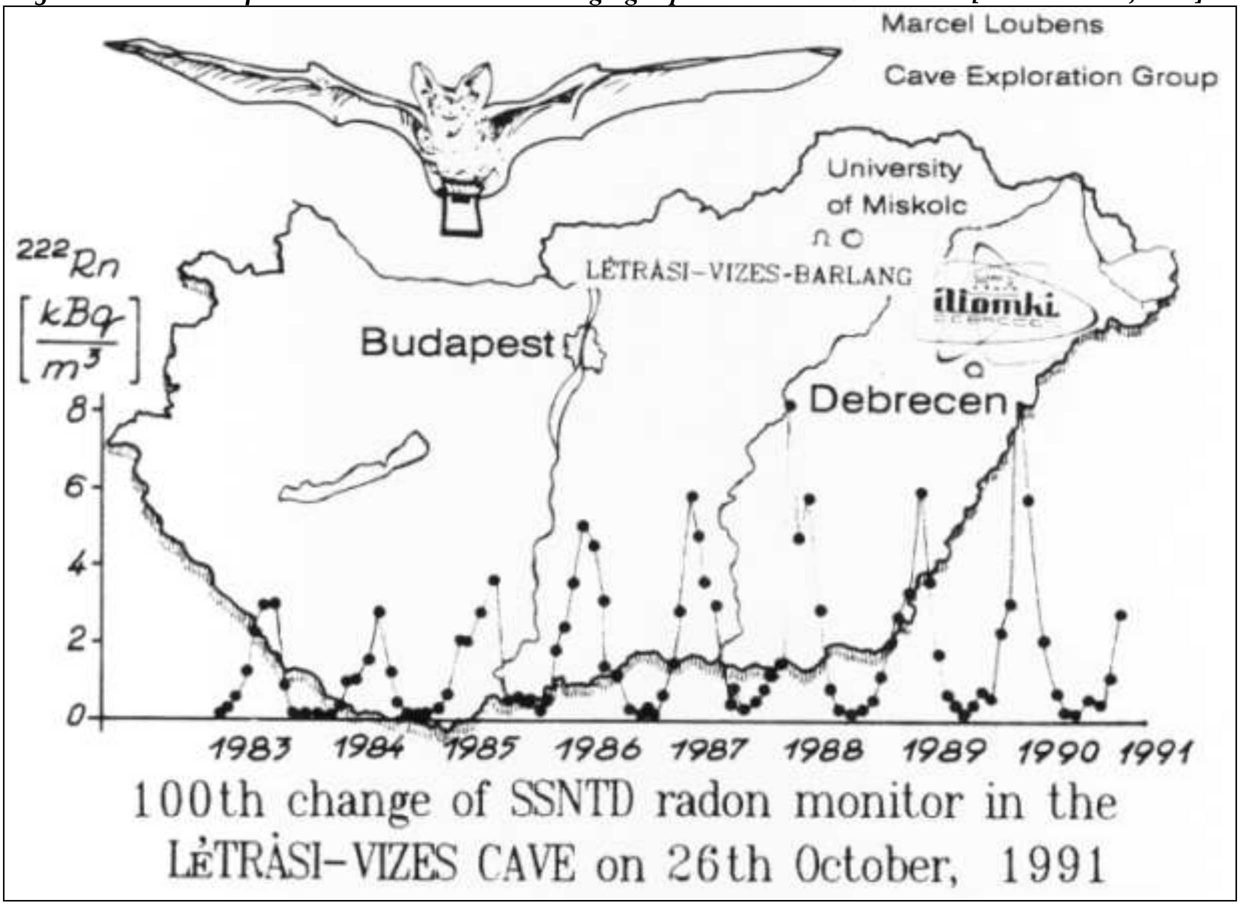


Fig. 3.5.3 The postcard published for the occasion of the 100th Radon detector changing trip of the Létrási-Vizes Cave [Original, 1991]

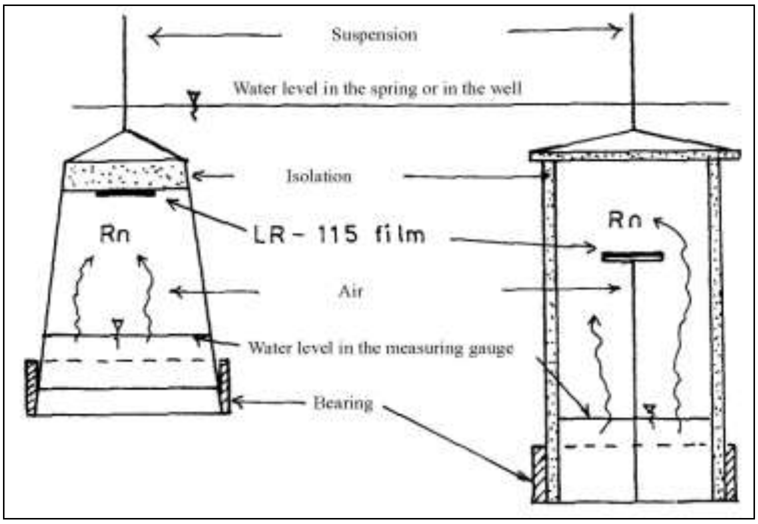


Fig. 3.5.4 Radon detecting "diver-bell" in the Létrási-Vizes cave No. 12 drip-measuring tank [Original, 1993]
Fig. 3.5.5 Radon detecting "diver-bells" and the principles of measurement [Lénárt et al, 1993]

The 100th Radon detector changing trip (which took place after 9 years of monthly changing trips) was celebrated by publishing a postcard which showed a Radon activity curve of many years ***(Figure 3.5.3***).

Figure 3.5.4 shows the Radon detecting device placed in a drip measuring tank. (Since the intensity of dripping is not too great compared to the half-life of the Radon the results were generally low in this case. ***Figure 3.5.5*** shows the principles of measuring in water.)

Figure 3.5.6 shows the Radon activity concentration based and depending on the geological features. The highest value can be measured in springs emerging from detrital shale, the lowest in springs emerging from travertino.

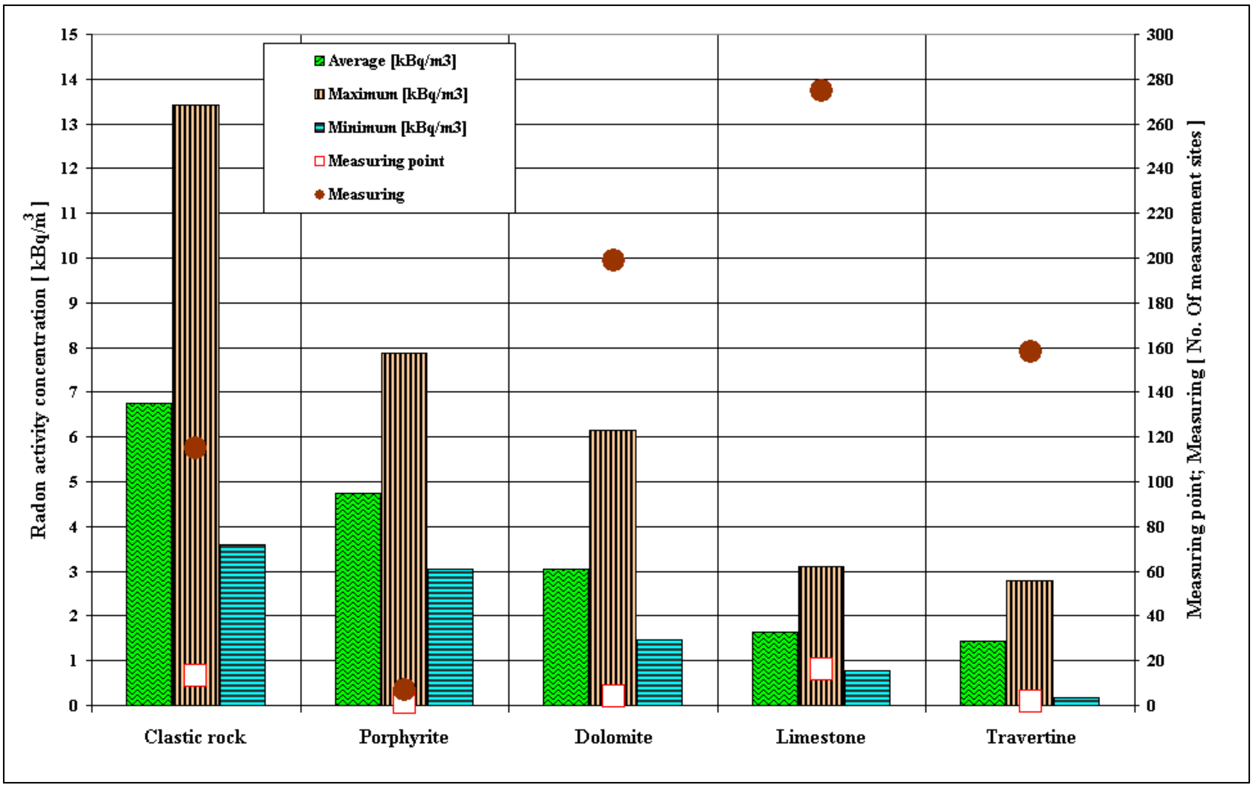


Fig. 3.5.6 The relationship between the Radon activity concentration and the surroundings' geological features [Lénárt et al., 1993]

The value of Radon activity concentration measured in the airspace of apartments and in the karst water used shown on ***Figures 3.5.7-3.5.8***.

The extent of the Radon concentration mostly depends on the kind of rock it moves through and the kind of rock it emerges from. In a measurement session taking many years in the Bükk it was proved that the highest average Radon concentration of the water was in the water emerging from detrital shale (6,76 kBq/m^3), next was water emerging from the porphyrite (4,74), then the dolomites (3,05), limestone (1,63), and finally the water emerging from travertino (1,45 kBq/m^3) ***[Somogyi and Lénárt, 1986a,b; Hakl et al., 1989, 1993; Lénárt et al., 1990, 1992, 1993, 1997; Lénárt, 1991]***.

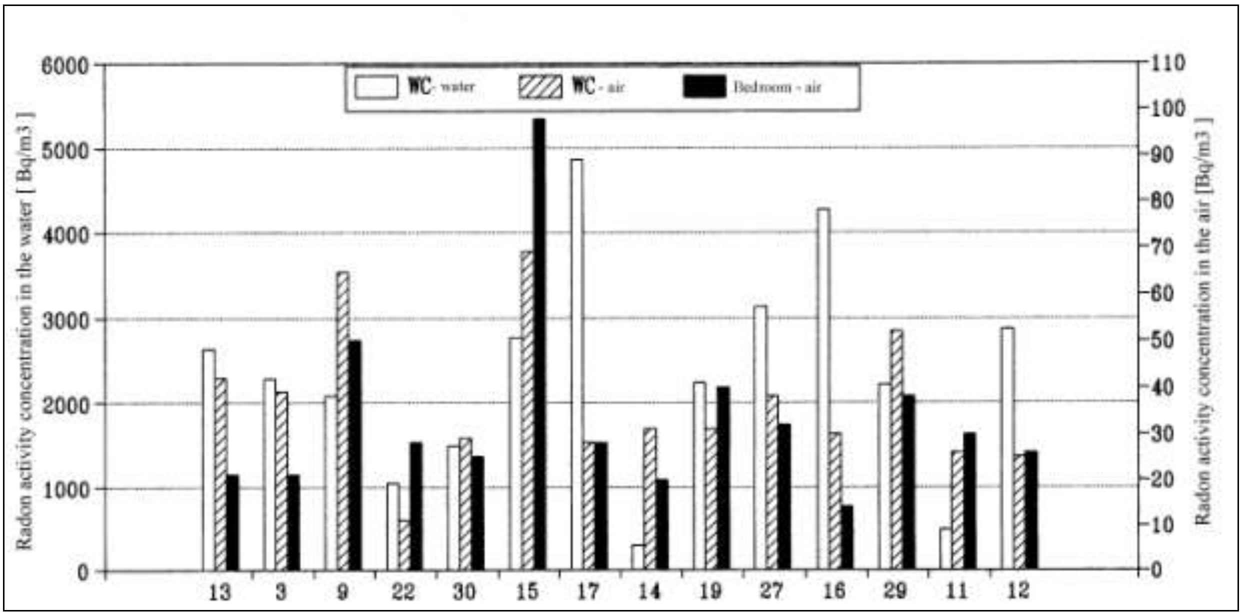


Fig. 3.5.7 Radon activity concentration in the water and air of 14 concrete buildings of Miskolc [Lénárt et al., 1994]

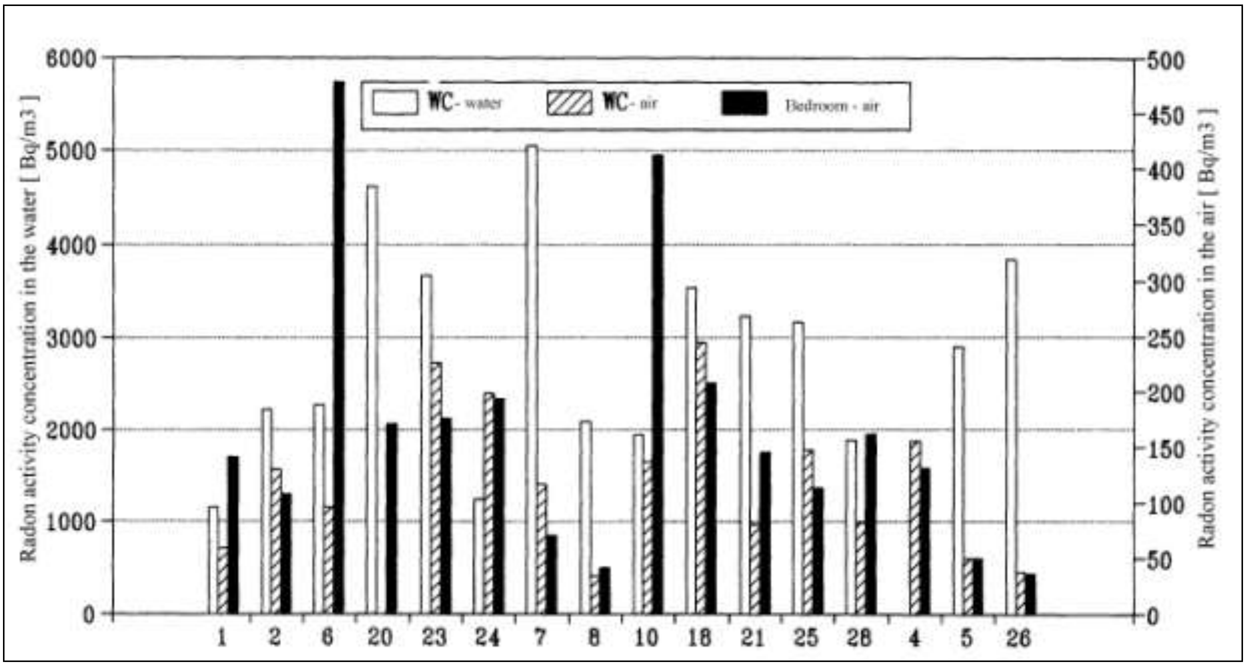


Fig. 3.5.8 Radon activity concentration in the water and air of 16 brick buildings of Miskolc [Lénárt et al., 1994]

4. Economic issues

Many questions regarding economy could be discussed in this chapter. I would like to highlight the importance of keeping caves clean. The most economical approach is to prevent pollution in karstic areas. (Naturally, it would be important to discuss the economical issues in more detail, but not in this study.)

It is a well-known fact that the karstic areas are highly sensitive to pollution. One kind of pollution is when the pollutants are washed into the karst water through water sinkholes.

Caves can be a potential threat to water quality due to the potential of concentrated source of contamination.

There are a large amount of caves in our study area. Their number, size and other properties will be discussed in more detail in the following chapter. Due to the topic of the paper I have to mention that the caves might fall into two main categories based on water protection aspects:

- caves that might slightly endanger the water exploited by water companies
- caves that potentially endanger the water exploited by water companies

The caves that might slightly endanger the water exploited by water companies are the ones which are small, not very deep, are in a distance from springs and the karst water level. The clay fill-up in them blocks the way of polluting material completely or at least decreases that.

The caves that potentially endanger the water exploited by water companies are the following:

- the spring caves that are in water company spring areas,
- caves that have corridors or shafts which are close to the karst water level, or are at karst water level,
- the most significant active sinkhole caves,
- the open shaft caves that are located close to inhabited places,
- the caves which are located close to roads,
- the caves which are visited heavily and frequently,
- the deep shaft-caves or shafts, regardless of their location.

The caves that potentially endanger the water exploited by water companies fall into three categories, based on their hydrogeological layouts and connections. This was determined by detailed and throughout field analysis:

- caves in which serious technical intervention and/or yearly monitoring check, and the removal of polluting material suggested,
- caves in which serious technical intervention not, and monitoring check only in every 2-3 years suggested; the removal of polluting material suggested,
- caves in which serious technical intervention not, and monitoring check only in every 4-5 years suggested; the removal of polluting material suggested.

In case of the potentially dangerous caves (regarding the pollution of the karst water) there is a high chance of pollution of the spring waters through the listed caves. For this reason I find systematic monitoring of these caves highly advisable. Also important is the removal of polluting material, or, in certain cases, the serious intervention for the protection of karst water. (This could be, for example, a pollution-blocking object or artifact placed at the mouth of the sinkhole.)

In the introduction of this chapter we have to state that in case of karst water we can talk about a special case of the „polluter-pays" principle. It means that from the water management point of view it is much easier to prevent pollution of the karst than to clean the water later and make somebody pay for it – for example, the water user, since the polluter is usually not known. The following actions had been taken by the water producers and the state for this prevention:

- delineation of open karst protected zones on all three of the study areas,
- delineation of confined karst protected zones in the Bükk,
- the determination of relationships and connections between sinkholes and springs had been done partly in all three of the areas, using water tracing technique,
- the measuring and the elimination (or at least starting the process of elimination) of pollution sources, both legal and illegal, on all three of the areas,
- the measuring of the pollution material in the caves of the Bükk, and the elimination of the pollution as much as possible,
- three national parks can be found on the study area,
- the caves of Aggtelek Karst and the Slovak Karst (Gömör-Tornai/Gemer-Turna Karst) are part of the World Heritage,
- the setting up of ramsar sites, connected to the Baradla Cave; in both national parks,
- biosphere reserves can be found in both national parks,
- all springs and sinkholes in the Bükk National Park and Aggtelek National Park are "ex lege" protected areas,
- in both countries, all caves are protected or highly protected.

4.1. Caves in the area, and their influence on water quality

Figures 4.1.1-4.1.3 helps to size up the natural values, including the caves, in our study area.

Figures 4.1.2-4.1.3 show the present zone boundaries as it is accepted by the environmental authorities. In case of the Aggtelek National Park this zonation is only complete together with the zones of the Slovak Karst National Park, but on the Slovak side there is no accepted decision yet. (According to verbal information exchange, the fitting together of the zones of both areas will take place in the future.) It is clearly visible that a significant part of the national park can be visited freely. (The Baradla Cave can be found in this freely visitable zone. This cave is the biggest of the area and also the most significant for tourism.)

In case of the Bükk the zone system is a little different. The ratio of the freely visitable areas is much smaller. This results in heavier use of these areas, which might have an impact on the environment. (All tourist caves fall into these zones.) Besides this, the Bükk National Park had established a „buffer zone", which gives significant protection against the effects of agricultural activity that comes from southeastern edge of the area.

4.1.5. The number and length of the caves, and their location in the study area

Many caves can be found on all three study areas. A wide range of studies had been published regarding the locations and the number of them. Let me mention a few of these without an aim to mention all ***[Strömpl, 1912; Bertalan, 1943; Benický, 1950; Borbély, 1955; Kučera, 1962; Bystricky, 1964; Erdős and Lysenk, 1966; Droppa, 1967, 1973a,b;***

Skřivanek and Rubin, 1973; Hradecký et al., 1974; Kučera et al., 1981; Erdős, 1984, 1995; Hlaváč, 1986; Stibranyi and Ženiš, 1986; Bella, 1988, 1996; Stibranyi and Petrik, 1989; Hazslinszky, 1992; Kósa, 1992; Lénárt and Balláné, 1992; Pástor, 1995; Erdős and Lalkovič, 1996; Lalkovič,

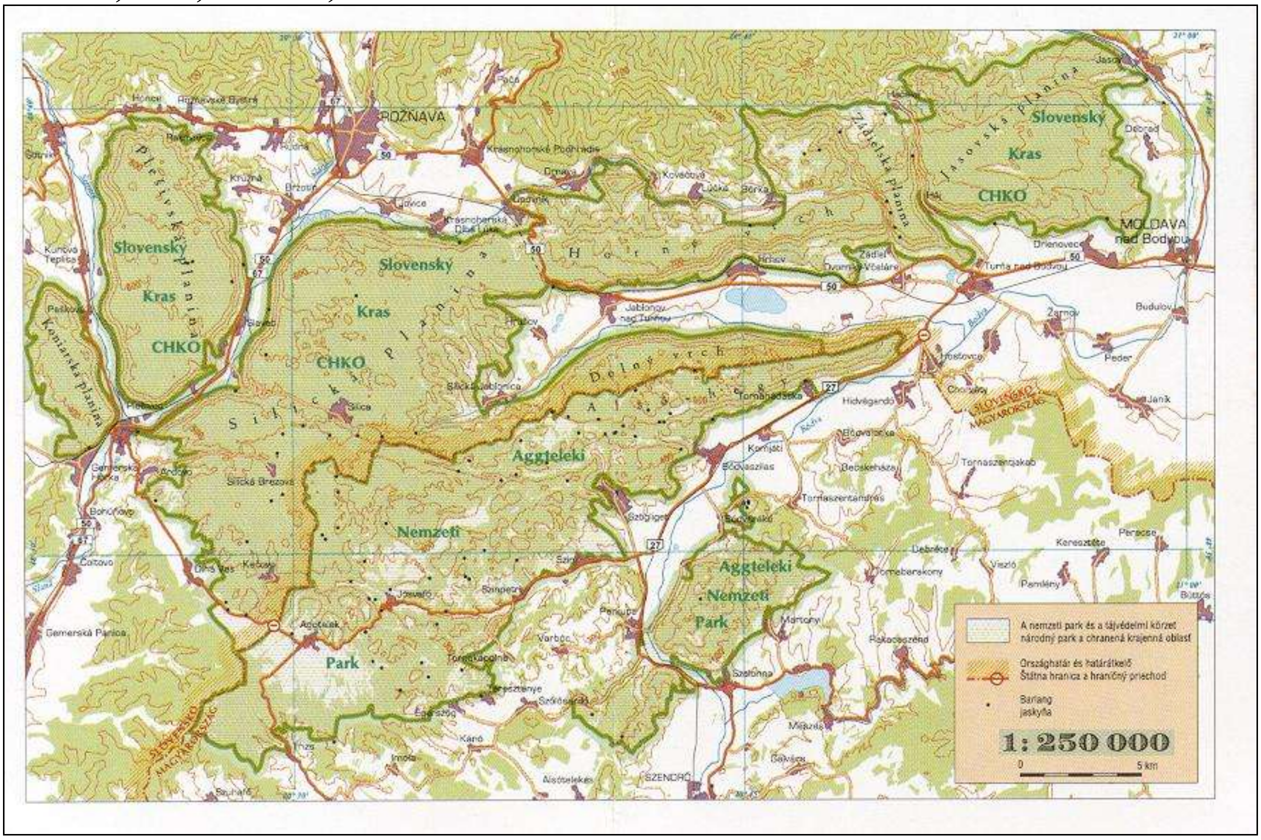


Fig. 4.1.1 Border of the Aggtelek Karst National Park and Slovak Karst National Park [2005]

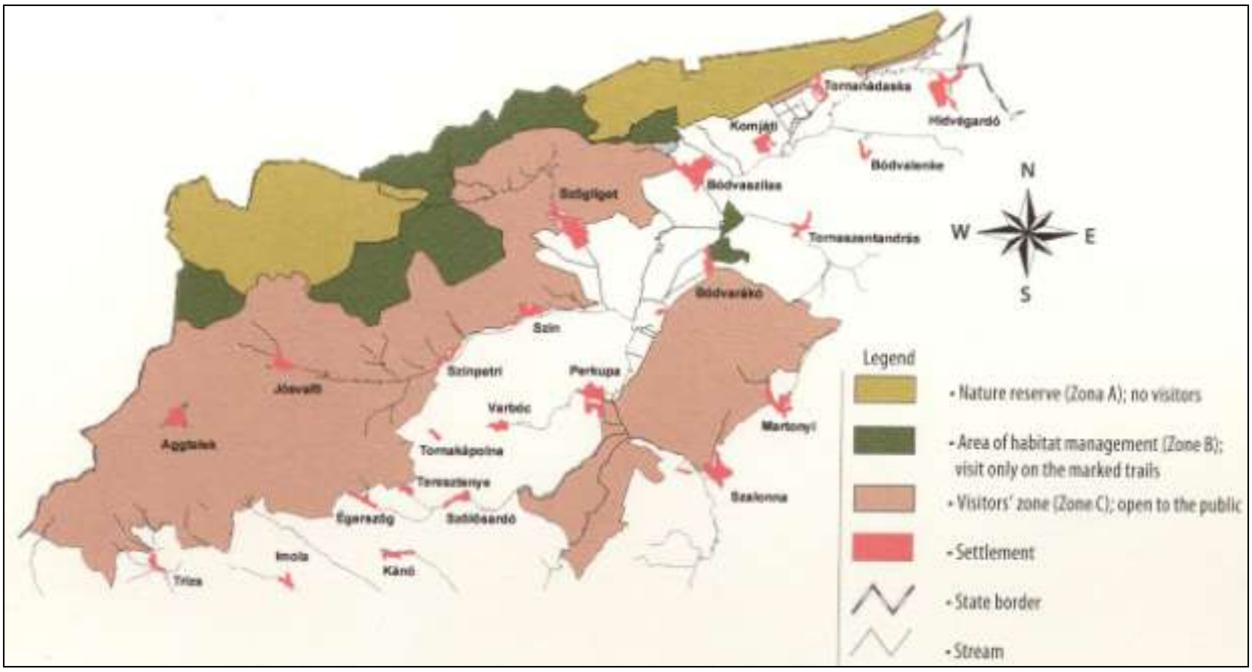


Fig. 4.1.2 The protected zone system of the Aggtelek National Park [2005]

1997; Gaál and Vytřisal, 1997; Tencer, 1998; Bella and Holubek, 1999]. The caves are relevant elements of the environment and the national parks. The locations of the caves in the Aggtelek Karst and the Slovak Karst are shown on ***Figure 4.1.4***. The locations of the entrances of highly protected caves of Hungary are shown on ***Figures 4.1.5a-4.1.5b***, based on the work of ***Székely [2003]***.

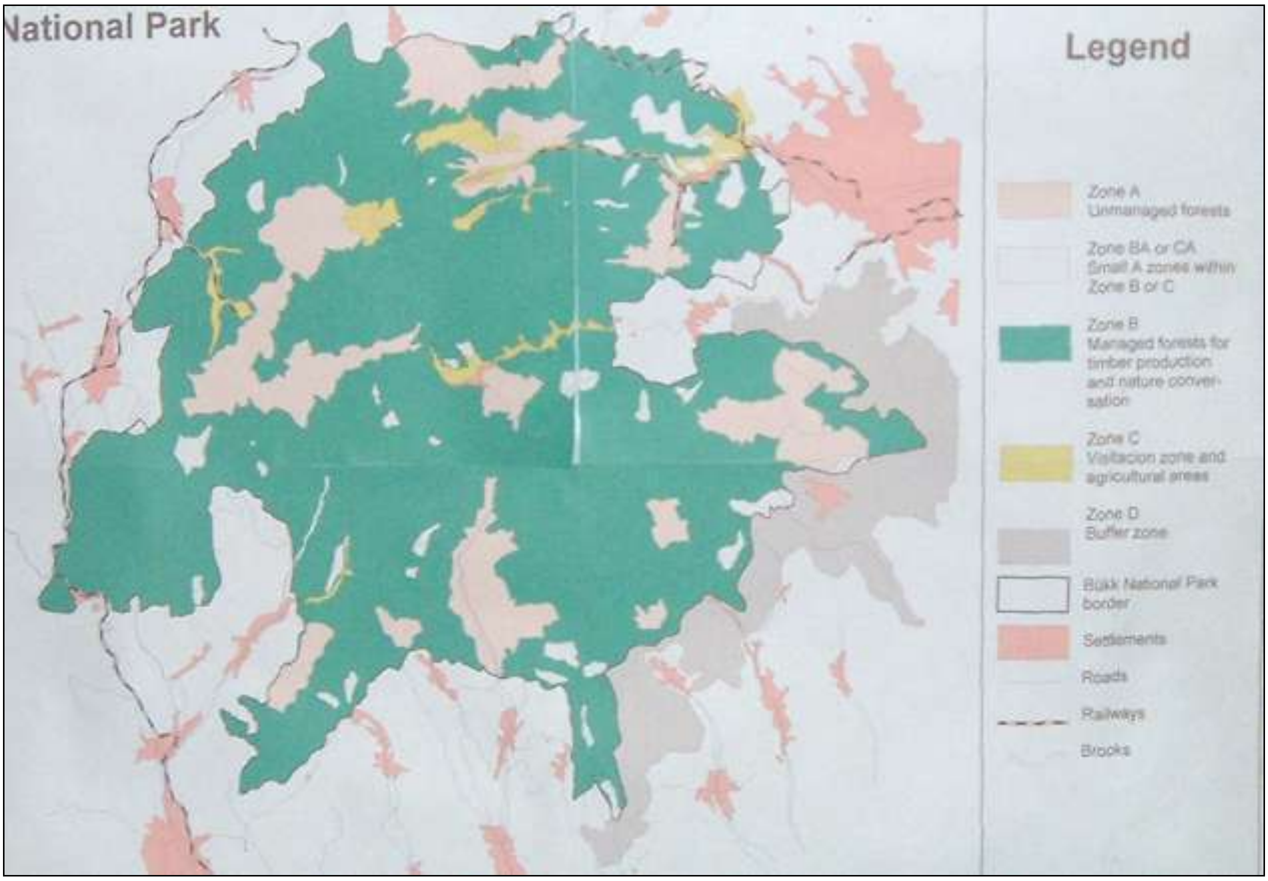


Fig. 4.1.3 The protected zone system of the Bükk National Park [2003]

The examination of the cave maps of the three areas clearly shows that the character of the caves on the study area is very different from each other and these differences can be quantified ***[Lénárt and Lénárt, 2004]***. (Because the largest cave system of the area, the Baradla-Domica cave system is situated in two of the study areas, I will use the old name of the Aggtelek Karst and the Slovak Karst, Gemer-Turna / Gömör-Torna Karst.) These characteristics are as follows:

- Most of the caves are located in the Bükk (979 caves).
- Most of the caves longer than 100 m are located in the Bükk (54 caves).
- The caves of the Bükk have the lowest average length (50 m, that is only the 25 % of the average cave length in the Aggtelek Karst, 62 % of the average cave length of the Slovak Karst).
- Most of the „small caves" are in the Bükk (cave ruin, length is between 2-10 m) (660 caves, 67,4 %).
- The total length of the caves of the Gemer-Turna / Gömör-Torna Karst (87.393 m) is almost the double of the total length of the caves in the Bükk (49.176 m).

- The longest cave is located at the Gemer-Turna / Gömör-Torna Karst (25.564 m, Baradla-Domica cave system).
- The caves of the Bükk are grid-like both spatially, both in plane (y = 30,764x-9029,4; and y = 0,0051x+8,3369).
- The caves of Aggtelek Karst are situated in the smallest volume of rock (y = 1886,5x-286586).

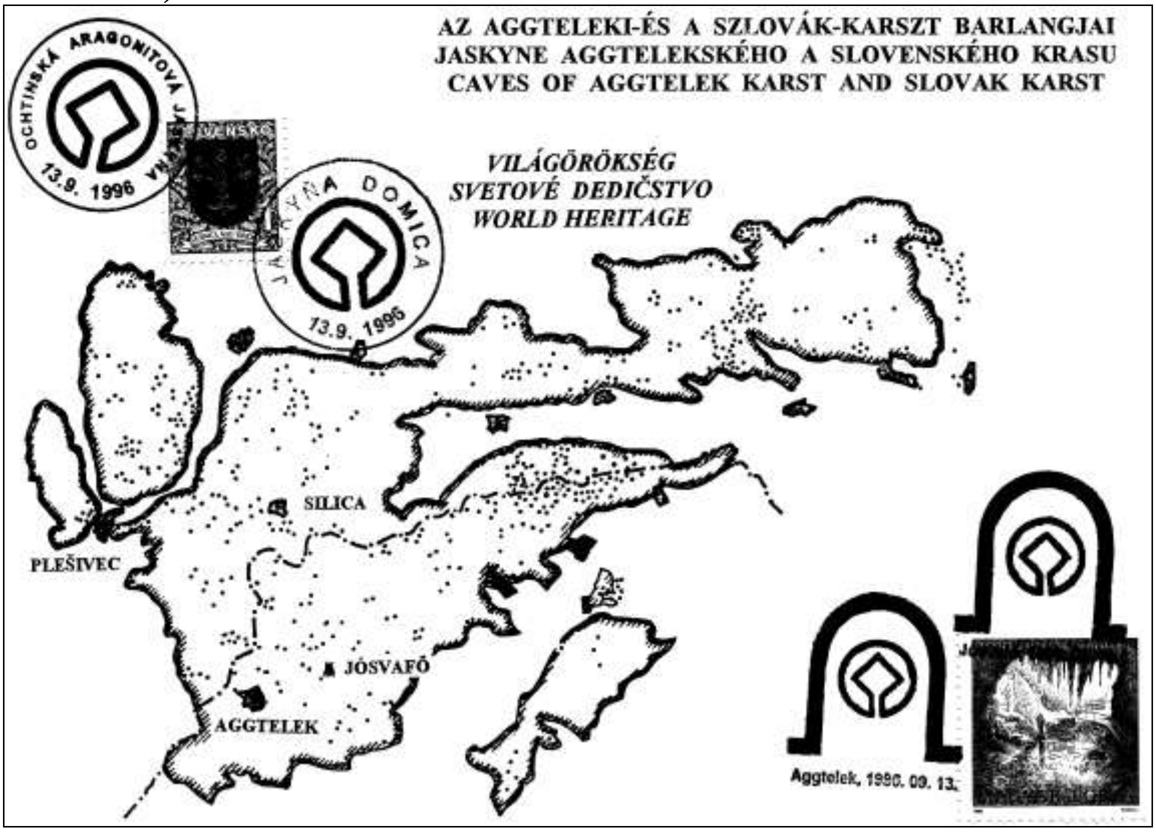


Fig. 4.1.4 Locations of the caves of Aggtelek Karst and Slovak Karst
[World Heritage occasional postal card and occasional postal cancellation, Original, 1996]

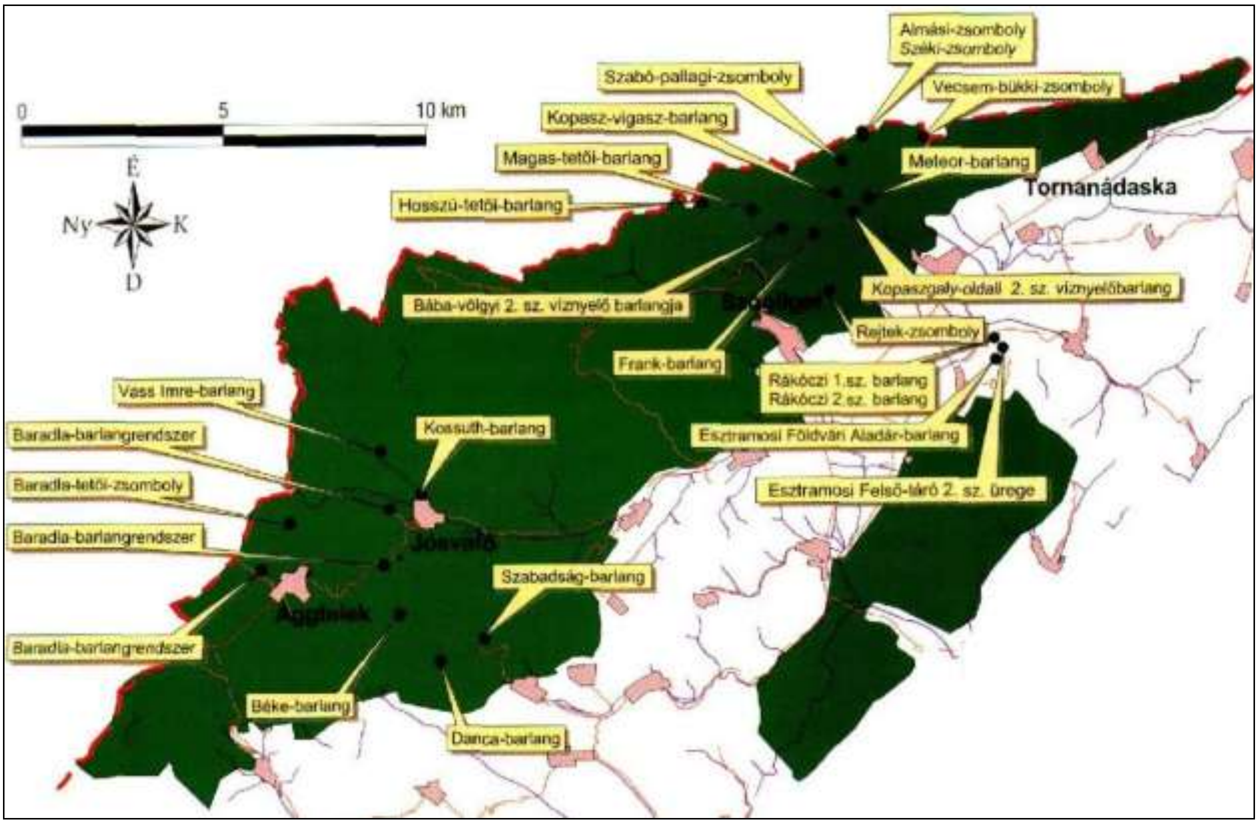


Fig. 4.1.5a Locations of the highly protected caves of Aggtelek Karst [Székely, 2003]
(Legend: barlang = cave; barlangrendszer = cave system; zsomboly = shaft-cave)

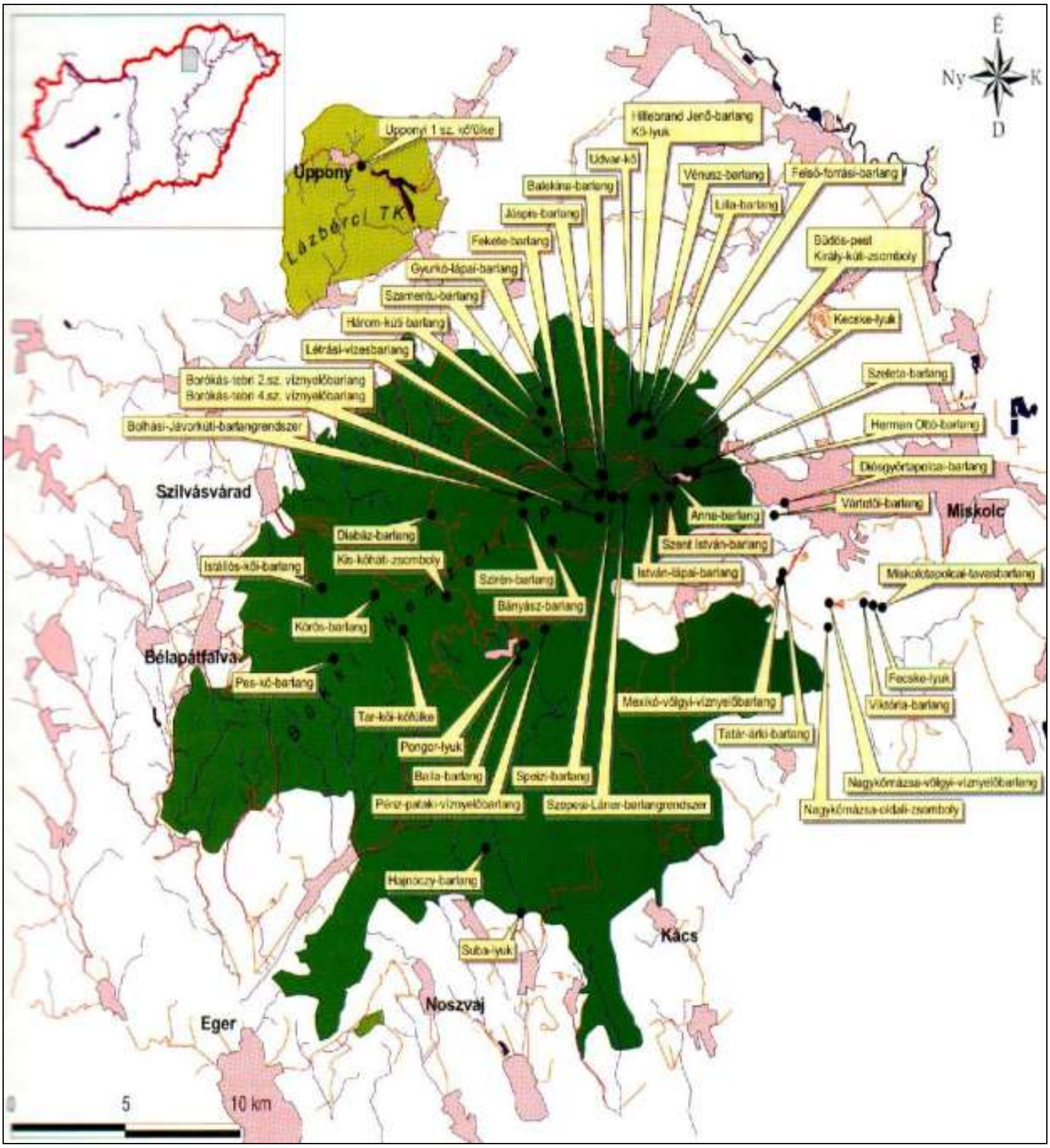


Fig. 4.1.5b Locations of the highly protected caves of Bükk Mountains [Székely, 2003]
(Legend: barlang = cave; barlangrendszer = cave system; zsomboly = shaft-cave; tavasbarlang = lake-cave; víznyelőbarlang = sinkhole-cave; lyuk = hole; kőfülke = rock shelter)

Figures 4.1.6-4.1.7 shows two partial maps of the Slovak Karst National Park – showing the location of the caves of the Silice Plateau and of the area around Jasov. The first is the work of ***Zacharov [1999]***, the latter is the work of ***Zacharov and Tometz [2001]***.

Let me note that there are very good tourist maps of all three areas which mostly marks the caves very precisely. Usually some information is also gives regarding the features and depths of the caves. (Also very important that more and more maps portrays the Gömör-

Tornai/Gemer-Turna Karst as one inseparable unit again, showing the political boundary. A very good example of this is the map by Paulus, which contains information in 4 languages.)

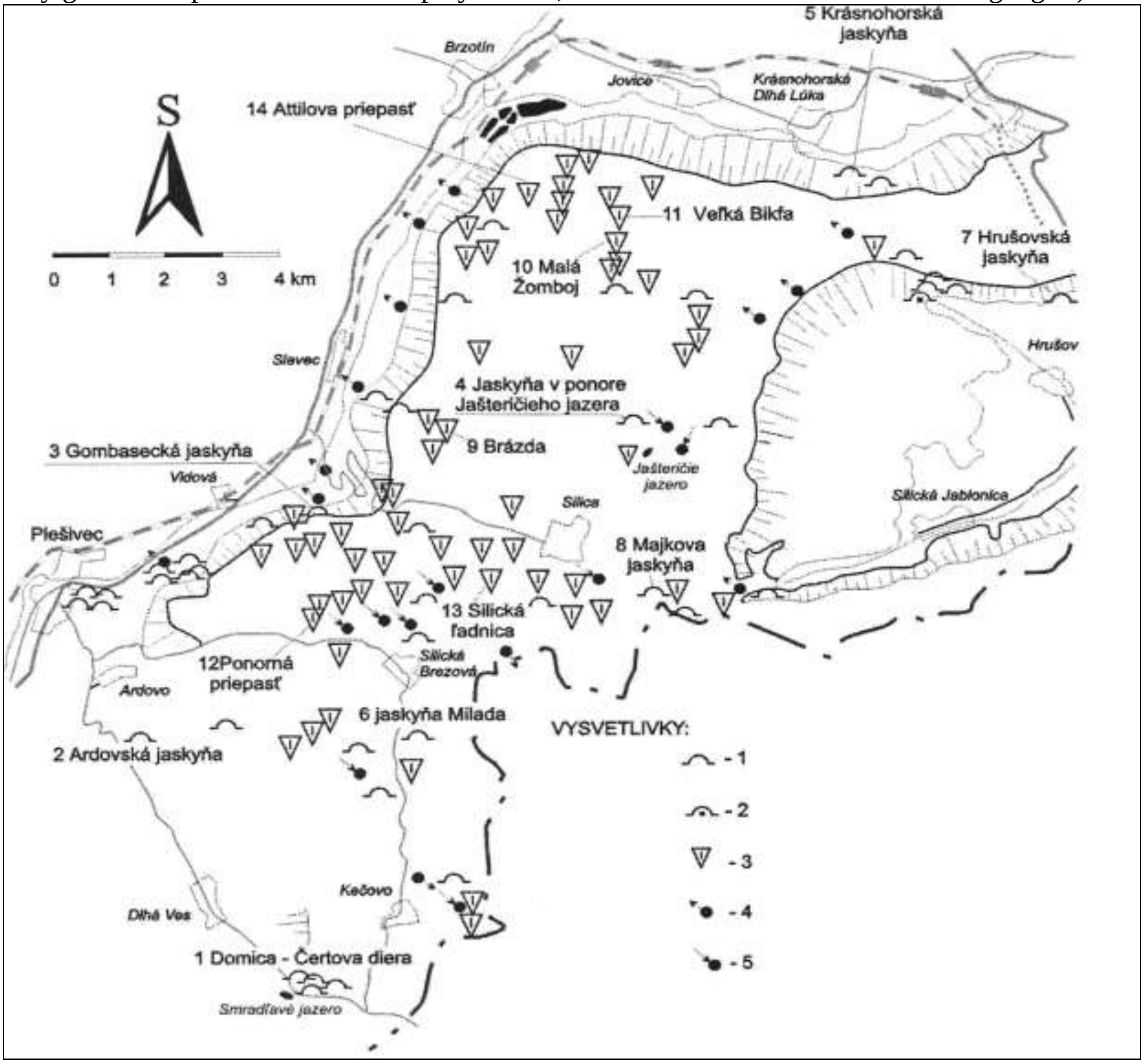


Fig. 4.1.6 Locations of the caves of Silica Plateau
[Zacharov and Tometz, 2001, after Erdős, 1995; Lalkovič, 1996; Zacharov, 2001]
(Legend: 1: jaskyňa = cave; 2: jaskyňa v travertínoch = cave in travertino; 3: priepast' = shaft-cave; 4: vyvieračka = spring; 5: ponor = sinkhole)

The outstandingly high number of small caves in the Bükk is probably due to natural causes, but also due to human activity (road construction, shafts, mining, etc.). In case of Esztramos the average is higher because of the mining activity – many caves had been destroyed – but the most part of the remaining caves are large ones ***[Lénárt and Lénárt, 2004]***. Some of the most important characteristics regarding caves are shown on ***Figure 4.1.8***.

To introduce the features and characteristics of these caves let me present a few photographs of inside and outside, and some cave maps. Most of the illustrations refer to the possible meeting between Man and water. I would like to prove the importance of the karst water protection through caves with these pictures as well.

Figure 4.1.9 shows the Esztramos Hill. For almost 40 years limestone mining had taken place here. During this time over 50 caves were discovered, and many of them were abolished. For a long time this was a very typical scene of the conflicts between environmental protection and industry in Hungary. A wide variety of works can be found with references to this situation,

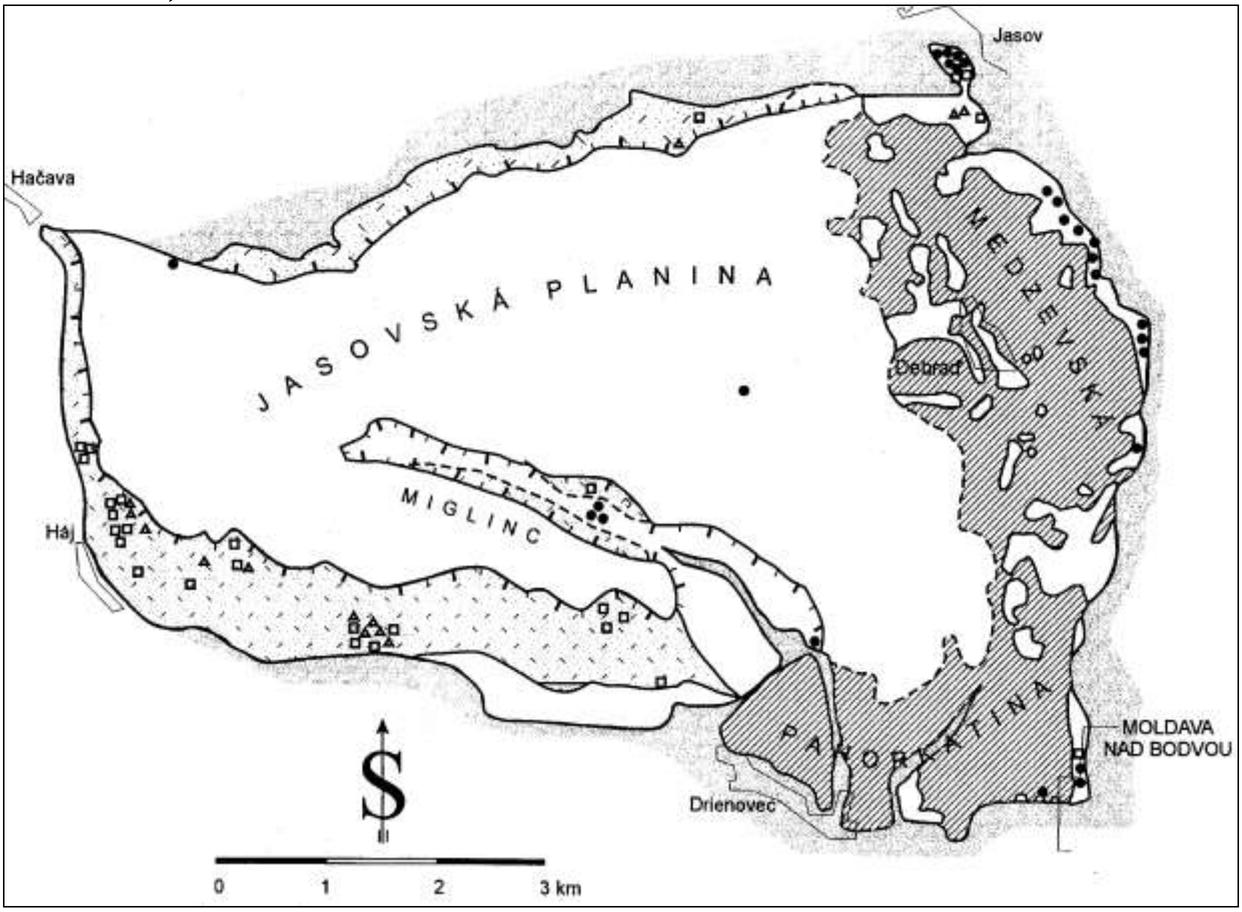


Fig. 4.1.7 Locations of the caves of Jasovská Planina Plateau [Zacharov, 1999]]
Legend: triangle: shaft-cave; circle: fluvial cave; square: fissure cave

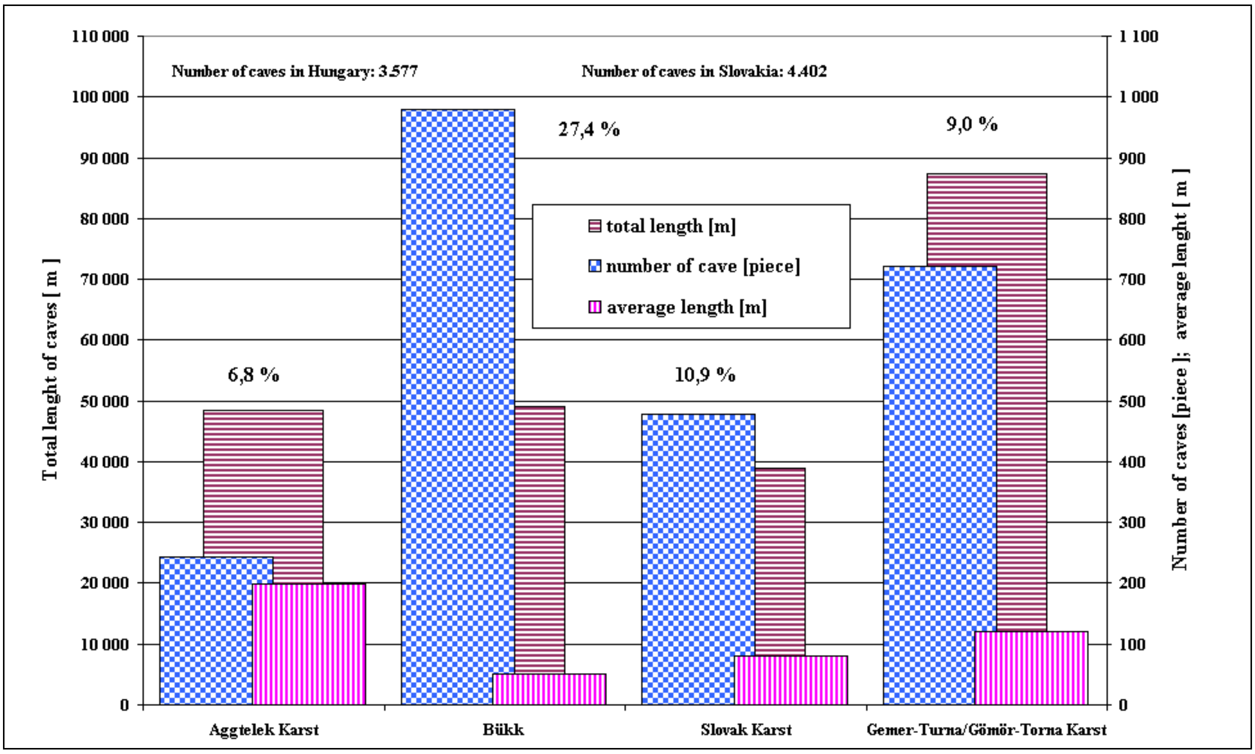


Fig. 4.1.8 The parameters of the caves [Original, 2004]

starting from daily news all the way to serious international studies, but unfortunately the hydrogeological research was not very rich in the area. Some of the hydrogeological works are ***[Forstinger, 1970; Dénes, 1983; Kordos, 1983; Takácsné, in: Baross, 1998]***.

The Esztramos Hill is the northernmost member of Rudabánya-Tornaszentandrás Range ***[Lénárt, 1997a]***. (Today it is part of the Aggtelek National Park.) It is built up mainly by Triassic, Wetterstein limestone. Most of the caves were formed in this formation, along fractures of 70-80° dip angle in the direction of NE-SW, NNE-SSW, N-S, NNW-SSE, NW-SE structural lines. In the large caves in the lower part of the area lakes with water of 11°C and 10-14° hardness. These lakes are in hydrological connection and underwater cave-parts open from them. The caves in the upper parts are open in some cases they are filled by debris or clay. These caves have only dropping water which carry aboveground pollution (in the area 0.01-1.00 m/day seepage factor can be estimated.)

The accidental discovery due to the mining of limestone was first report by S. Borbély in 1961. This article was followed by scientific and educational reports, and as public information, articles, special lectures, parts of books, newspaper articles, radio and television reports, all about 250, in the following decades.

In my thesis of engineer-specialist (1990) I managed to identify 52 former and recent caves (in some cases cave-groups). Besides the 22 caves found in the area of the mine, about 80 are supposed to have been, but there is no written information about them. 28 of them still exists, and 24 were destroyed during mining. 4 caves are highly protected because of their beauty and variety of forms. The total volume of the caves is estimated to be the 1.5-3.5 % of the including rocks that is a particularly large cave-density.

The genesis of caves is still debated during this processes several warm and cold water phases followed each other. The caverns in the level higher than 320 m aBs level might have been the oldest caves in Hungary, as they had a free air-space even in the Upper Pliocene.

Fig. 4.1.9 The view of Esztramos Hill, the "beheaded mount" [Original, 2005]

The Földvári Aladár and Rákóczi I. caves ***(Figure 4.1.10)*** were opened and set up for the speleological tourism at the 10th International Speleological Congress in 1989.

Many scientists have done work regarding the natural values and their protection of the Esztramos Hill. One of the most important is the works of ***Koleszár [1999, 2000]***.

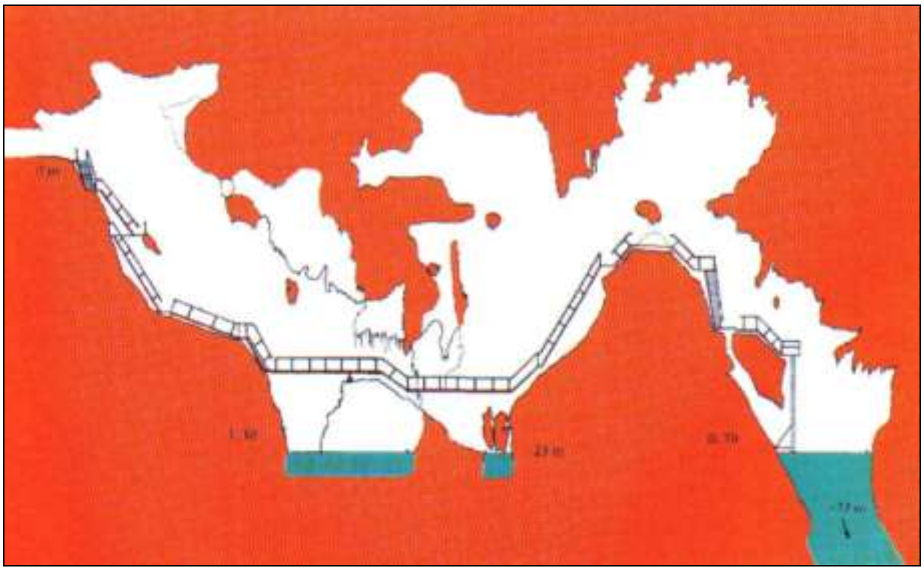


Fig. 4.1.10 The map of Rákóczi I. cave of Esztramos Hill [Székely, 2003]

In the preface titled Personal motivation I already noted that my first cave visit abroad had taken place in one of the caves of the Gömör-Tornai/Gemer-Turna Karst. The Ardovská Cave was over the political boundary. This trip was very important and very dear to me, and let me recall it with this photograph taken of the participants ***(Figure 4.1.11)***.

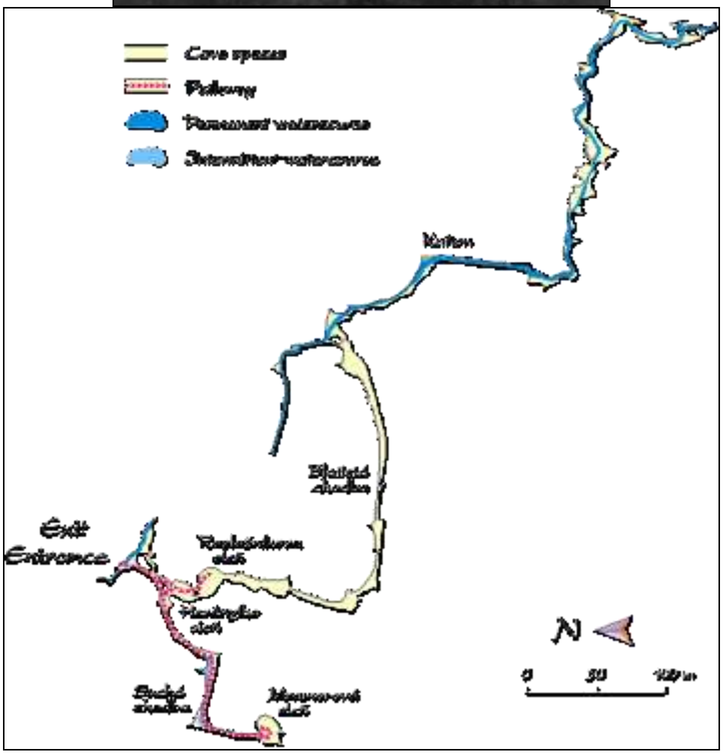


Fig. 4.1.11 A group of cavers in the Ardovská Cave [Original, 1974]
Fig. 4.1.12 Map of Gombasecka cave in Slovak Karst National Park [http://www.ssj.sk/]

Let me present the map of the Gombasecka Cave of the Slovak Karst National Park ***(Figure 4.1.12)***. As we can see, the people visiting the cave can come into immediate contact with the karst water.

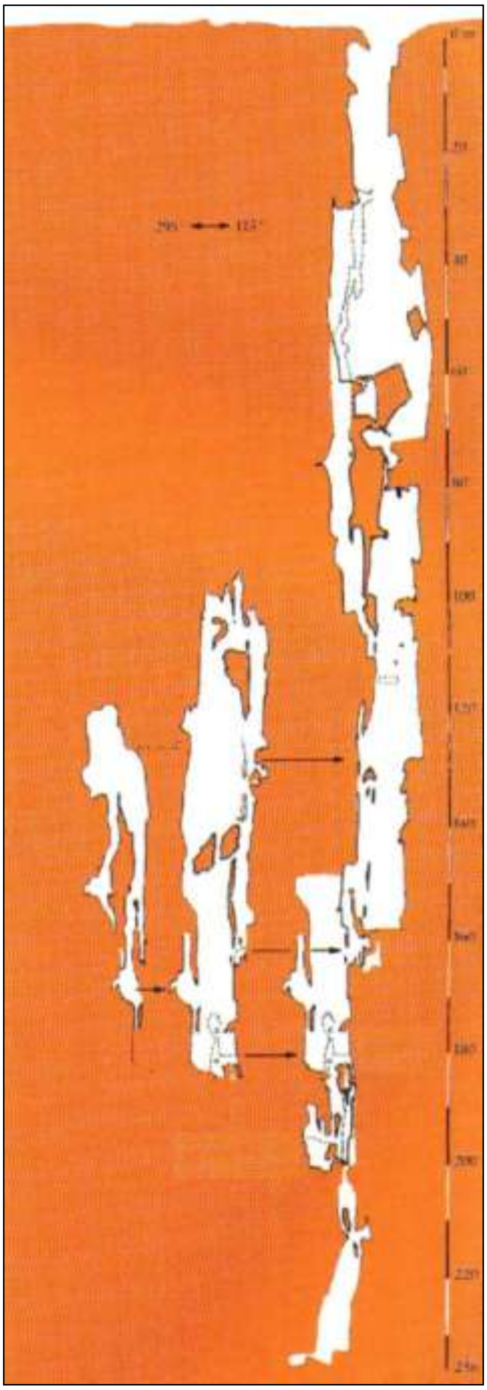
A very spectacular example of the meeting between karst water in the cave and the speleologist is the No. 4 siphon of the István-Lápa Cave. It is the most magnificent siphon of the Bükk with its 90 m length. (My first serious cave mapping, when I was a university student, came to this point.) Photograph by Attila Kiss ***(Figure 4.1.13a)*** and Gergely Maucha ***(4.1.13b)***. The István-Lápa Cave is the deepest cave of Hungary; its map is shown on ***Figure 4.1.17***.

Fig. 4.1.13a István-lápa cave, No. 4 siphon, precipitation-free period, clear and clean water [Kiss, 11.12.2004]

Fig. 4.1.13b István-lápa cave, No. 4 siphon, after snow-melting, muddy water [Maucha, 02.04.2005]

Among the large caves of Hungary, the map of the Vecsembükk Shaft-cave -cave is presented on ***Figure 4.1.14***. It is the deepest cave of the Aggtelek Karst. It doesn't reach karst water level yet but there is a strong chance for the cavers of doing so sooner or later. ***Figure***

4.1.15 shows a section-map of the Pénzpataki-Sinkhole Cave of the Bükk. At the bottom of this cave is a seasonal water surface. The documented water level fluctuation can be as much as 90 m! The fluctuation of the nearby Répáshuta karst water monitoring borehole (Tbp-1, ***Figure 3.4.4***) probably exceeds this limit, but since the drill is shorter than necessary I cannot detect the karst water level here.



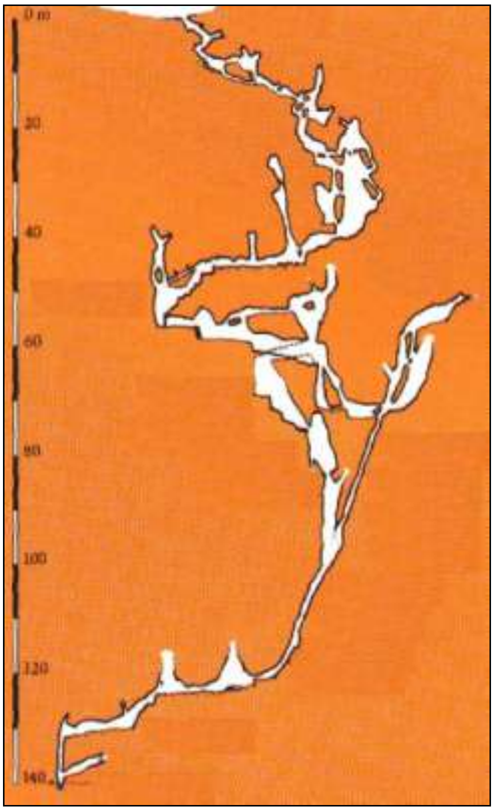


Fig. 4.1.14-4.1.15 The map of Vecsembükk Shaft-cave (Aggtelek Karst) and Pénzpataki Sinkhole-cave (Bükk Mountains) [Székely, 2003]

From the water protection aspect, the relationship and connections between the caves and springs is very important. Many scientists had researches into these water connections

[Borbély, 1955; Hazslinszky, 1965; Dénes, 1965; Sárváry, 1971; Jakucs, 1977; Böcker and Dénes, 1977, 1978; Orvan, 1979, 1995; Lénárt, 1983b; Blaha, 1988; Kullman, 1990; Jansa, 1990; Maucha and Sárváry, 1994; Havas, 1995; Móga, 1998; Maucha, 1998; Sásdi, 2000; Tometz, 2000; Zacharov and Tometz, 2001; Izápy and Maucha, 2002; File, 2004], partly from the aspect of speleology, partly from the aspect of water protection. Let me present a few of these just for sampling, without aiming to mention them all.

Tometz in ***2000*** had used part of the information about the water connections of the Silica Plateau to evaluate the impact of "Friendship" oil pipe to the environment. The following works belong to this topic as well: ***Tometz and Orvan, 1996; Tometz, 1999; Blišt'an et al., 2000; Blišt'an and Tometz, 2000; Tometz, 2000a,b***. ***(Figure 4.1.16)***

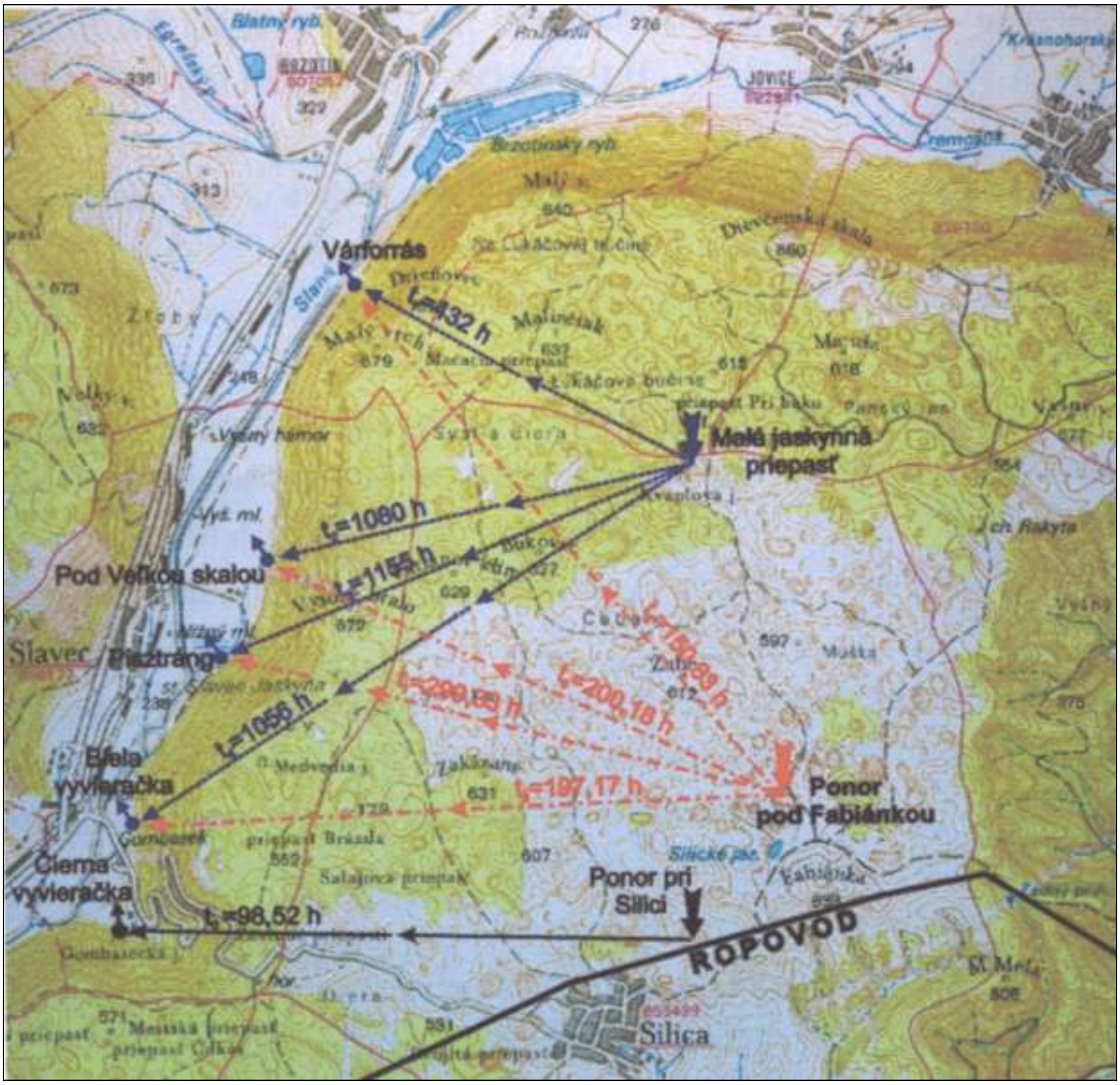


Fig. 4.1.16 Water connections of the Silica Plateau in the surroundings of the "Friendship" oil pipe (ropovod)
[Tometz, 2000] (Legend: t = tracer water (poured into sinkholes) exiting in springs, marked in hour)

The water tracing analyses in the Miskolc area had taken place for mainly water protection reasons, but of course we had tried to use this data for speleological purposes as well. ***File [2004]*** shows on ***Figure 4.1.17*** the sinkholes, caves and springs in their geological surroundings. In certain cases the water tracing took place in a cave. (Yellow color shows 8 caves of the most significant area of the Bükk with regards to caves, among them the István Lápa Cave with its layout map, which is the biggest in the Bükk and the deepest in Hungary.)

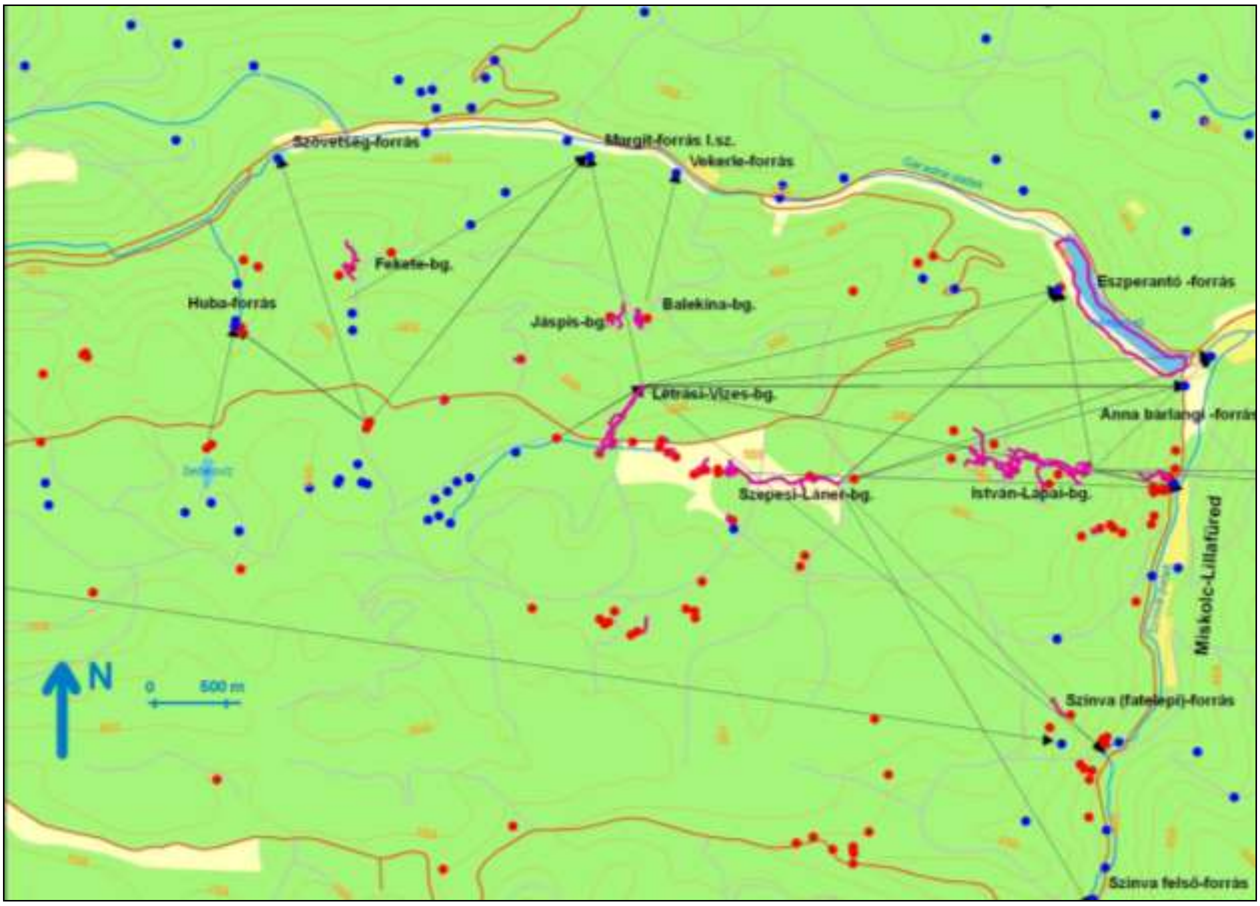


Fig. 4.1.17 Water connections in the Eastern Bükk, in the surroundings of the production "Szinva" and "Anna" springs [File, 2004] (Legend: bg = cave; forrás = spring; tó = lake; red point = sinkhole; blue point =spring; black narrow = effective tracer test)

At the end of this chapter we must talk about the points where the water emerges from the karst. These are partly deep-drilled boreholes ***(Figures 4.1.18-4.1.19)***, partly springs engaged in water production ***(Figures 4.1.20-4.1.25)***. The seasonal karstic springs must be mentioned as well as really interesting phenomenons. They are the best indicators for the changes in the karst water level ***(Figures 4.1.26-4.1.27)***.

Fig. 4.1.18-4.1.19 Thermal karst water exploitation from the wells of Miskolc (Augusztus 20 bath II. well; water works well) [Original, 2004]

Fig. 4.1.20-4.1.21 Karst water exploitation from the springs of Miskolc ("Garadna" Spring) [Original, 2004] (Water emerging from dolomite, water level measuring with DATAQUA measuring device)

Fig. 4.1.22-4.1.23 Karst water exploitation from the springs of Miskolc ("Szinva" Spring) [Original, 2004] (Water emerging from limestone)

Fig. 4.1.24-4.1.25 Karst water exploitation from the springs of Miskolc ("Anna" and "Margit" spring) [Original, 2005] (Water emerging from travertino and dolomite)


Fig. 4.1.26-4.1.27 The Vörös-kői seasonal spring in its active period; it is one of the seasonal karst springs of the Southern Bükk [Debnár, 2004, 2005]

4.1.6. The strain on the caves and their protection

4.1.6.3. Protection of the caves

Every cave is protected under law in Hungary. 51 caves are located in the Bükk, 23 located on the Aggtelek Karst out of the 135 increased protected caves ***[Székely, 2003]***. The situation is very similar in Slovakia.

Three national parks are situated on the study area: Bükk National Park, Aggtelek National Park, Slovak-Karst National Park. All three are mountain area, and protected because of their karstic formations and caves ***[Rajman et al, 1971, 1988; Timčak et al, 1973; Bartus et al., 1982; Jakal et al, 1982; Zacharov, 1984; Roda et al, 1988; Bolfik, 1990; Rozložnik and Karasová, 1994; Baross et al., 1996; Bella and Klinda, 1996; Jakal, 1996, 2000; Baross, 1998; Baráz, 2002; Lénárt and Takácsné, 2002]***. The number and location of the caves area being shown on ***Figures 4.1.4-4.1.8***.

The caves of the Aggtelek Karst and Slovak Karst are part of the World Heritage since 1995 ***[Bolner-Takács and Székely, 1995; Székely and Takácsné, 1996]***. In both countries, in the Baradla-Domica cave system there are ramsar sites ***[Gunn, 2004]*** and biosphere reserves ***[Bartus et al., 1982]***.

The delineated hydrogeological protected zones for caves in case of Bükk ***[Tóth, 2002]*** offer special protection. Further delineation of hydrogeological protected zones are in process both in the Bükk, and in Aggtelek.

Many caves are locked with door from tourists and visitors on all three areas. Closed means that these caves cannot be visited freely, only on certain conditions, with tour guides; in some cases they cannot be visited at all. This is very important from the karst water protection point of view. The reasons for the closing of caves are the following:

- Tourist caves (8 caves altogether)
- Caves used for medicational purposes (4 caves altogether)
- Caves used for water exploitation (3 caves altogether)
- Caves closed for research purposes and for scientific work (1 cave)
- Caves closed for environmental protection purposes (75 caves altogether)

The list of locked caves in the Aggtelek National Park:

1. Baradla Cave (6 entrances altogether)
2. Béke Cave
3. Szabadság Cave
4. Kossuth Cave
5. Vass Imre Cave
6. Meteor Cave
7. Rákóczi Cave
8. Földvári Cave
9. Felső-táró No.2. Cave
10. Surrantós Cave
11. No. 404 Cave
12. Hosszú-Alsó Cave
13. Rövid-Alsó Cave
14. Baradla-tetői Shaft-cave
15. Rejtek Shaft-Cave
16. Teresztenyei Spring-cave
17. Vörös-tói Shaft-Cave

The list of locked caves in the Bükk National Park:

1. Anna Cave (3 entrances)
2. Balekina Cave
3. Bolhási-Jávorkúti Sinkhole-cave, Bolhás entrance
4. Bolhási-Jávorkúti Sinkhole-cave, Jávorkút entrance
5. Borókás-No. 2. Sinkhole-cave
6. Borókás-No. 4. Sinkhole-cave
7. Bronzika Cave
8. Diabáz Cave
9. Diósgyőrtapolcai Cave
10. Esztáz-kői Cave
11. Fecske-lyuk Cave
12. Garadna Spring-cave
13. Gyurkó-lápai Cave
14. Hajnóczy Cave
15. Hillebrand Jenő Cave
16. Szent István Cave
17. István-lápai Cave
18. Jáspis Cave
19. Király-kúti Spring-cave
20. Kő-lyuk Cave
21. Létrási Vizes Cave I. entrance
22. Létrási Vizes Cave IV. entrance
23. Lilla Cave

24. Mexikó-völgyi Sinkhole-cave
25. Miskolctapolcai Lake-cave
26. Szalajka Spring-cave
27. Szamentu Cave
28. Szepesi-Láner Cave system (Láner Olivér entrance)
29. Szepesi-Láner Cave system (Szepesi entrance)
30. Vár-tetői Cave
31. Vénusz Cave
32. Viktória Cave

The list of locked caves in the Slovak Karst National Park

1. Ardovská Cave
2. Domica – Čertová Cave
3. Domica – new entrance
4. Domica – stream
5. Domica Cave
6. Diviačia Shaft-cave
7. Drienovská Cave
8. Gajdova štôla – Teplica
9. Gemerskoteplická Cave
10. Gombasecka Cave
11. Hačavská Cave
12. Hrušovská Cave
13. Cave v ponore Jašť. jazero
14. Cave Skalistého stream
15. Cave na Kečovských lúkach
16. Jasovská Cave
17. Kamenná pivnica Cave
18. Krásnohorská Cave
19. Krulova baňa Cave
20. Kunia Shaft-cave
21. Matilda Cave
22. Marciho Cave
23. Medvedia Cave
24. Milada Cave – No. 2 entrance
25. Milada Cave – grand entrance
26. Mníchovská Cave
27. Moldavská Cave
28. Nová brzotínska Cave
29. Okno Cave
30. Prastarý výver Cave
31. Shaft-cave Kóta
32. Shaft-cave pod Hajagošom
33. Silická Icecave
34. Strieborná Cave
35. Vápenná Cave
36. Zúgó Cave
37. Majková Cave

Ferenczy Gergely, Gruber Péter and Ludovit Gaál gave me the list of closed caves in 2004.

4.1.6.4. Attendance of caves

The evaluation of cave attendance is important due to the danger of karst water pollution. Unorganized groups of visitors can create the most serious problems.

Most of the caves („small caves") of the study area can be visited freely. It is difficult to gather data about the number of visitors.

The maintenance of the more important caves is being done by amateur speleologist groups. Permission must be asked from the authorities to visit these caves. The reports of the speleologist groups contain information about the number of visitors in the caves. The attendance depends on the characteristics and the reputation of the caves. The most important „sport caves" are being visited by a few hundred people per year. (The „sport caves" are caves longer or deeper than 100 m. There are 54 such cave in the Bükk, 32 on the Aggtelek Karst, 44 on the Slovak Karst. In altogether 130 caves, the number of visitors per year is roughly 40 000 person.)

Nowadays the term „tourist cave" is also known. These are „sport caves" with admittance fee and guide. (In Slovenia and Croatia this is serious income for the speleologist groups.) The organization level of this is low; the assessed numbers of visitors are much lower in this category of caves.

The caves built-in for tourism purposes can be visited without permission, but for a fee ***[Balázs, 1962-1975; Pástor, 1996; Lalkovič, 1997; Hazslinszky and Lénárt, 2001; Lénárt and Stuhán, 1999]***. Their usage as follows:

- The Baradla cave is very important on the Aggtelek Karst; subject is the Béke cave, the Vass Imre cave and the Kossuth cave for serious admittance. Since 1951, on average a yearly 154.483 person visited these caves, which is 27,7 % of the total number of visitors on all three areas.
- The most highly visited tourist cave in the Bükk is the Cave Bath, (Miskolctapolcai Tavas-cave), less visited the Szent István cave, less again the Anna sinter cave. Since 1954, on average a yearly 300.549 person visited these caves, which is the 23,7 % of the total number of visitors on all three areas.
- The most highly visited cave on the Slovak Karst is the Domica cave, less visited is the Ochtinska Aragonite cave, less is the Gombasecka cave and the Jasovska cave. Since 1951, on average a yearly 102.325.person visited these caves, which is the 18,4 % of the total number of visitors on all three areas.

Admittance in the part of caves used for medical purposes can be through doctor's prescription. Sufferers of sickness in the respiratory organs are treated in the Szent István cave of the Bükk, Béke cave of the Aggtelek Karst, and the Domica and Jasovska caves in the Slovak Karst. The numbers of patients treated are about 2000-2500 persons per year.

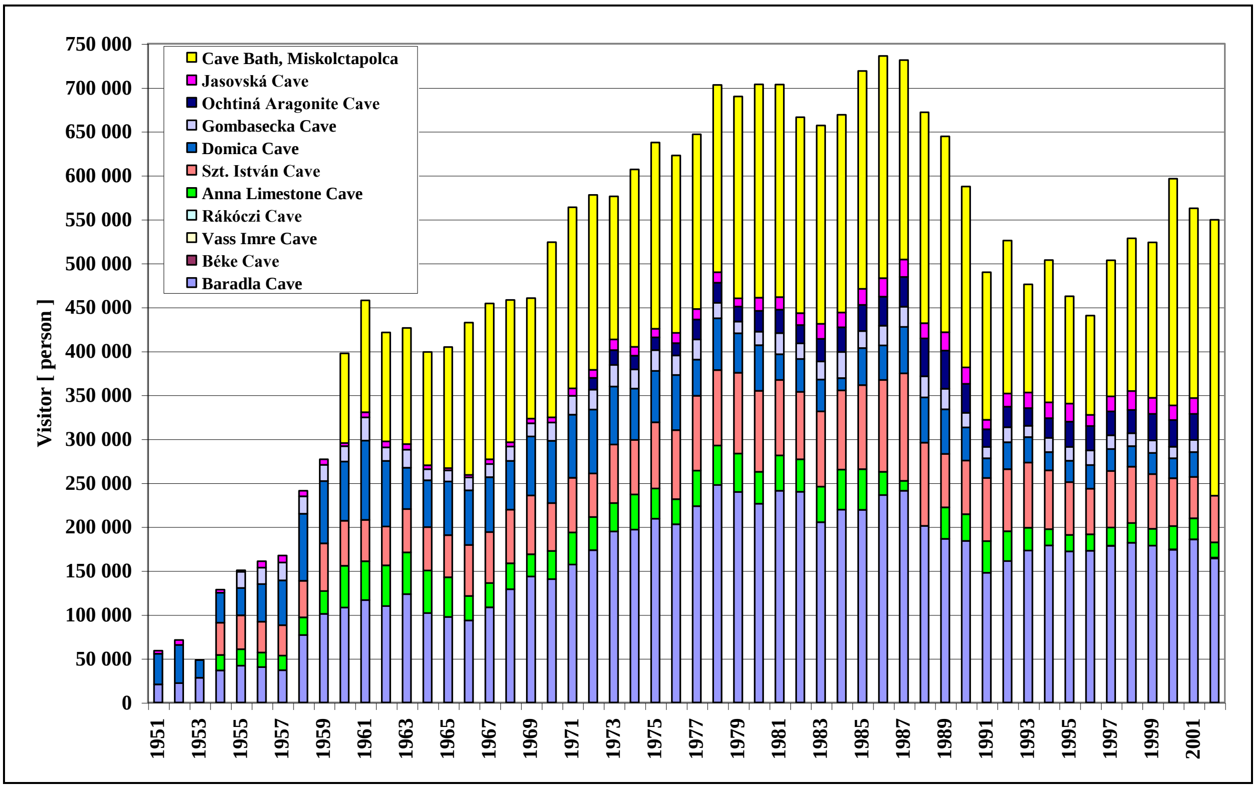


Fig. 4.1.28 The number of visitors in the tourist caves of the study area [Original, 2005; and based on Hazslinszky et al.]

4.1.6.5. Illegal pollution of the caves

Hojdákné [1992, 1994, 2002] grouped the pollution of the Bükk karst as follows:

- Communal waste water and garbage
- Agricultural animal keeping
- Forestry
- Mining, industry

Pollution of the caves is dangerous for the quality karst water in different rates. (The first group on the list could affect caves.) According to my evaluation in the Bükk, the caves that are near or reaching karst water level are the most potential danger source for pollution. The danger can be cut back by the systematic evaluation of the caves, by the information sessions given to speleologists, and by the cleaning out of caves of the polluting material ***[Borbély, 1955; Jancsó et al., 1997; Lénárt, 1998; Lénárt and Takácsné, 2002] (Figure 2.2.4-2.2.5)***.

Out of the 761 caves of the Bükk that had been evaluated until today, 94 mean more or less potential danger for the water company. It is very important to survey these caves in every 1 to 5 years. The danger of pollution is significantly lower if the garbage is being carried to the surface from the cave (cave cleaning).

The potential danger of pollution of an oil pipeline laid down under the Silice Plateau represents a specific problem ***[Bella, 1992; Tometz and Orvan, 1996; Tometz, 1996, 1999; Blišt'an et al., 2000; Blišt'an and Tometz, 2000; Tometz, 2000a,b,c]***.

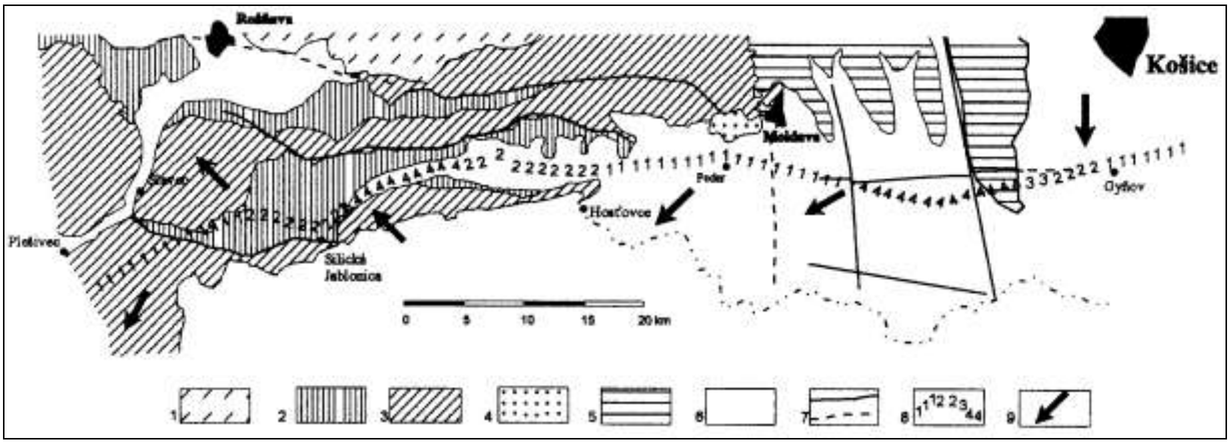


Fig. 4.1.28 Schematic map of vulnerability of the rock environment on Slovak Karst [Tometz, 1996] (Legend: 1: Paleozoic (quarcites and sandstones alternating with phyllite, low permeability); 2: Lower Triassic (marly shales and marly limestones, low permeability); 3: Middle Triassic (limestones and dolomites, karst and karst-fissure permeability); 4: Cretaceous (conglomerates, low permeability); 5: Neogene (impermeable clays with gravels and sands, middle permeability); 6: Quarternary (sandy gravels, high inter-granular permeability); 7: observed and inferred faults; 8: vulnerability of the rock environment regarding groundwater quality dividend into 4 groups; 9: direction of groundwater flow)

4.2. Protected zones, environmental values

On all three of the study areas many different kind of protection can be found. I think the most important is not the method of protection but the protection itself. All these different methods can complete each other and help the karst water protecting activity.

Due to this reason I will dedicate a separate chapter to the hydrogeological protection and environmental protection, but in a little bit separated way. These can make each other stronger, complete and in certain cases, can substitute for each other.

4.2.7. Hydrogeological protected areas and zones

The delineated hydrogeological protected zones for caves in case of Bükk ***[Tóth, 2002]*** offer special protection. Further delineation of hydrogeological protected zones are in process both in the Bükk, and in Aggtelek. The water protection is more important than the protection of other environmental values, such as caves or karstic areas – since the base of all life on Earth and the base of all environmental values is water.

The practical aspects of water protection are different due to the political boundaries, but the main idea behind them is the same: the long-term protection of the water reserves, nowadays in the spirit of WFT, since both countries are the members of the European Union.

There are 20 protected zone delineated on the Slovak Karst which protects water or karst water. These areas are all open karst and the protection is basically for the karst water coming from precipitation. The water emerges from the karst through karstic springs or bore-holes drilled in the karst. (In case of boreholes the exploited water sometimes comes from se-diments, but still part of the water is karstic in origin.) The size of these protected zones va-ries, but even the largest doesn't exceed 30 km^2. In cases of three of the Slovak protected zones (Dlhá Ves-Kečovo-Silická Brezová; Silica; Silická Jablonica) the political boundaries mean the administrative boundary of the zone and the water probably will not respect these boundaries. These are the areas where the regional cooperation would be very important, in this case for the Slovak interest ***(Figure 4.2.1, area No. 1-20)***.

6 protected zones are delineated or in the process of delineation on the Aggtelek Karst. (Some protected zone is being reviewed at a moment and this zone might be subject to resizing or decreasing.) These protected zones are usually very small, the largest doesn't exceed 7 km^2. (At Komjáti, regarding the Pasnyag spring, the situation described in the previous paragraph is present. The limit of the protected zone is the actual political boundary and the water will not take this into consideration. Regional cooperation should be created, in this case for Hungarian interests. The same situation is present, only on a smaller scale, on Jósvafő, in case of Babot-well) ***(Figure 4.2.1, area No.21-26)***.

The situation is more complex in case of the Bükk. Out of the 16 protected zones 6 is delineated administratively, but due to changes in law some of the first are already being revised. (All the others are in different phases of the delineation, usually very organized professionally.) The size of the protected zones are various here as well but the biggest – the protected zone serving the karst water exploitation of the Miskolc – is 291 km^2 altogether. 171 km^2 out of this is open karst, 120 km^2 is confined, closed thermal karst. (These are connected to each other very closely. In 1987 this was the first confined karst water protected zone in Hungary. Even though this area has no immediate contact with the surface, it is still very important because of the protection of the thermal karst water that lies in the deep.)

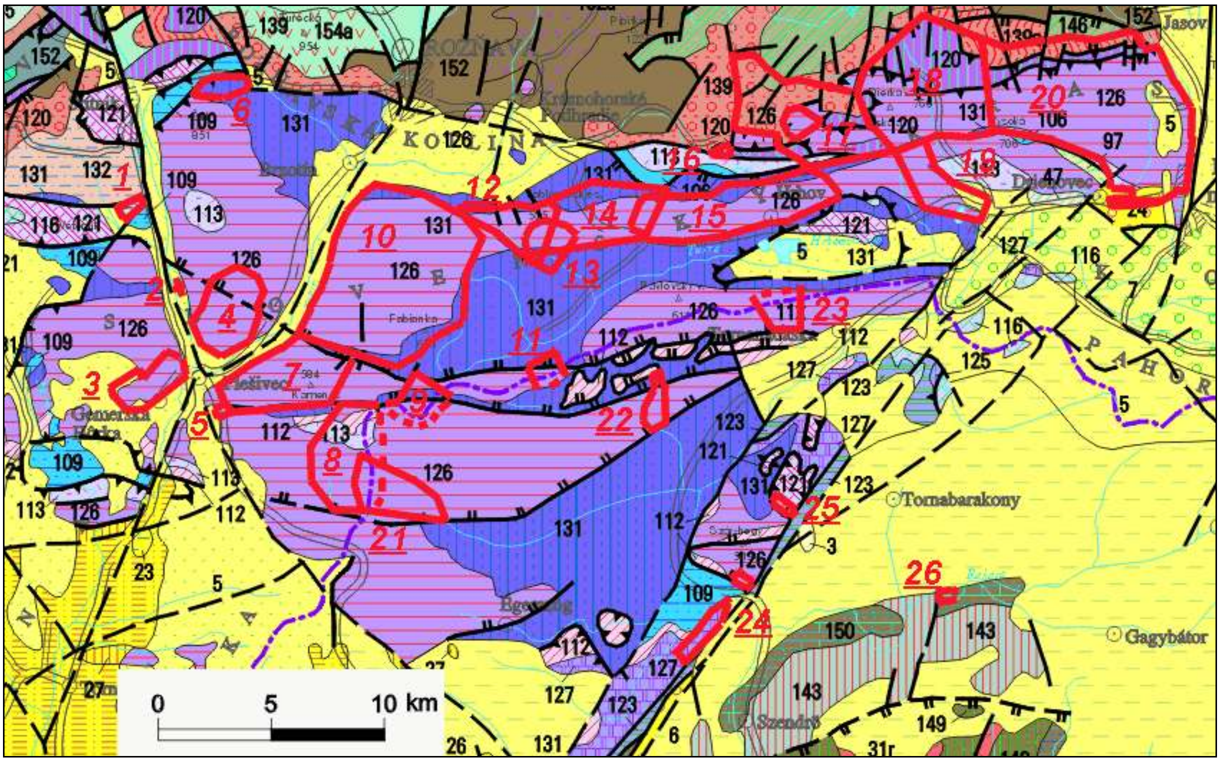
The protected zones – delineated or in the process of delineation – are producing karst water mostly and only in very small ratio they produce groundwater or fissure water that is feeding on karst water ***(Figure 4.2.1, area No. 27-41)***. (I did not show the protected zones that are clearly protecting waters originating from sediments.)

In case of the Bükk there are no problems regarding water reserve split by political boundaries, but unfortunately not everyone understands (or is willing to accept) the connections between cold and hot karst water. It is partly due to economical reasons since the increase in thermal water exploitation is already at the level of state politics, but still there is no conception for a long-term plan regarding reliable water management neither for the Bükk, nor for Miskolc. (The not very well aligned karst water exploitation is a worrisome thing since it probably shortly will lead to overexploitation, bringing decrease in water pressure and water level, yield and temperature in the Miskolc area ***(Figure 4.2.1, area No.41)***.

The situation is very similar in the Southern and Southwestern Bükk and in their surroundings. The thermal karst water exploitations in the area (Mezőkövesd, Bogács, Andornaktálya, Eger, and Egerszalók) for spa and medication purposes are not aligned. The existing production is increasing again, but the biggest problem represented by the newest exploiters who want to start taking out water with demands that exceeds the supplies. The water demand of the existing huge investments, the developments and the new investments in the region should be evaluated for the long-term and it should be compared to the possibilities ***(Figure 4.2.1, area No.35-38)***. (Unfortunately presently the government politics only supports this with so many words but with nothing else.)

The planned or delineated (or in the process of delineation) hydrogeological protected zones are presented on ***Figure 4.2.1***.

Legend to Figure 4.2.1; 1: Kunová Teplica; 2: Pašková; 3: Gemerská Hórka; 4: Plešivec (Plešivec Plateau); 5: Ardovo; 6: Honca; 7: Plešivec (Silica Plateau);8: Dlhá Ves, Kečovo, Silická Brezová; 9: Silica; 10:Rožňava; 11: Silická Jablonica; 12: Krásnohorská Dlhá Lúká; 13: Hrušov; 14: Jablonov nad Turňou; 15: Hrhov; 16: Lúčka; 17: Bórka; 18: Turňa, Drienovec, Košice (Zádielská Plateau); 19: Turňa, Drienovec, Košice (Turňa Basin); 20: Turňa, Drienovec, Košice (Bodva Basin); 21: Jósvafő; 22: Szögliget; 23: Komjáti; 24: Szalonna; 25: Martonyi; 26: Rakacaszend; 27: Mónosbél, Bélapátfalva; 28: Szarvaskő; 29: Eger-Almár; 30: Eger-Észak; 31: Felsőtárkány-Berva; 32: Felsőtárkány-Barátrét; 33: Bükkzsérc; 34: Noszvaj; 35: Eger-Petőfi square; 36: Egerszalók (confined thermal karst); 37: Andornaktálya; 38: Bogács (confined thermal karst); 39: Kács, Sály; 40: Miskolc (open karst); 41: Miskolc (confined thermal karst)


Jasov
Tornabarakony
Gagybátor
Szendrő
Plešivec
0
5
10 km

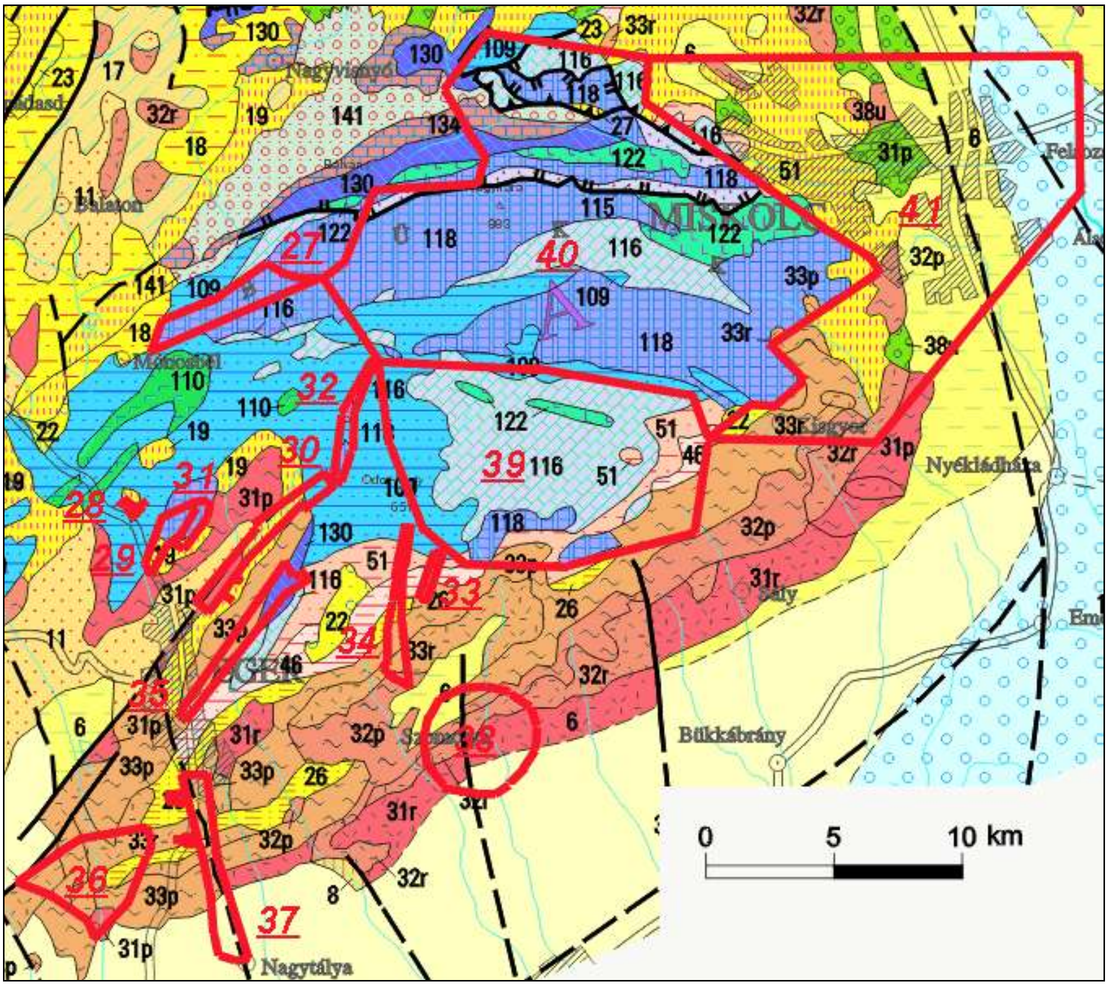

Nagyvisnyó
Balaton
MISKOLC
Nyékládháza
Bükkábrány
Nagytálya
0
5
10 km

Fig. 4.2.1 Hydrogeological protected zones [Original, 2005; after Buranová et al. 2004, and Koleszár, J. oral information, 2005] (See Figure 2.1.8 and previous page)

4.2.8. Environmental protected zones

All of the studied areas are environmentally protected zones. On one hand this means national protections (e.g. national parks, landscape protection zone), on the other it means international protection as well.

From the water resources protection point of view it means that the basically polluting activities, such as inhabited areas, industrial work, transit roads are either no in the area or they are strongly limited. There is a very intense tourism, though, which can be highly polluting, especially since they are mostly concentrated to certain areas (Lillafüred, Szilvásvárad, Szalajka Valley of the Bükk, and the surroundings of the entrances of the Baradla Cave in the Aggtelek Karst; Zádielská (Szádelő) Valley and Silice Icecave in the Slovak Karst).

The environmental protection tries to handle the crowd of people with the setting up of surface and very special underground educational paths in all three of the areas. The directing/information signs and the brochures of these educational paths are all emphasizing the importance of protection. The steps to be taken in order to protect the waters are almost nonexistent in this material so there is still a lot of effort and energy needed on both sides of the border.

Due to water exploitation, the protected areas are harmed in an indirect way. In the Bükk area there are many karst springs whose water is completely withdrawn for communal purposes. It means that there is absolutely no water coming from the spring or it only happens seasonally. (It must be noted that the conflicts are getting slowly resolved between the water companies and the environmental protection, but still there is a lot to do. Presently the human water consummation is decreasing. The reason for this is that the price of water is high and the people are getting more and more environment conscious. This was the ecological water resources are increasing, and it is detectable.)

The ecological water demands of the national parks are clearly portrayed in ***Gasztonyi [2002]***. The issue from the water companies point of view was written down by ***Vojtilla [2002]***, the opinion of the water authorities was represented in ***Uray [1994, 2002]***.

4.2.8.6. National protection

There are three national parks in our study area ***(Figure 2.1.1)***:

- Bükk National Park (Year of foundation 1976, Total area 43.130 ha, Strictly protected area 5.704 ha, administration centre Eger)
- Aggtelek National Park (Year of foundation 1985, Total area 20 169 ha, Strictly protected area 4.791 ha, Biosphere Reserve 19.274 ha, Biosphere Reserve Core Area 230 ha, administration centre Jósvafő)
- Slovak Karst National Park (Year of foundation 2002, Total area 34.611 ha, Strictly protected area 11.742 ha, Biosphere Reserve 36.165 ha, Biosphere Reserve Core Area 8.679 ha, administration centre Brzotin/Berzéte)

All three national parks are mountaneous areas, built mostly of karstic rocks. Because the most important issue is the environmental protection, usually there is no need for separated water protection program. Still, we should not forget, that the karsts are very sensitive to pollution so all environmental protection rules and water protection rules must be kept in all circumstances ***[Kullman, 1986, 1990, 1996; Hojdákné, 1992, 1994, 2002; Lénárt, 1994; Orbán, 1994; Gaál, 1996; Tometz, 1998a; Gogu and Dassargues, 2000; Jakal, 2000;***

Németh, 2001; Havas et al., 2003; Holló, 2003; Mádlné et al., 2003; Malik and Švasta, 2004].

On the Hungarian side, between the two national parks, the Lázbérc Landscape Protection Area can be found with 3.634 ha area, of which 683 ha are under increased protection ***(Figures 4.2.2-4.2.3)***. The main purpose is the water protection of the Lázbérc Lake, together with the environmental values. The area can be freely visited but the actual lakeside is only accessible with the permit of the Waterworks (available locally). The environmental protection handling is in the hands of the Directorate of the Bükk National Park, the water production and water protecting works are being done by the Northern-Hungary Regional Waterworks.

The landscapes of the Carpathian Basin were formed by the subsequent cultures of peoples replacing each other here for thousands of years, therefore, in contrast to the majority of nature conservation areas of the world, all of the Hungarian protected areas are cultural landscapes. The Lázbérc Landscape Protection Area is still unique as it was established to protect an area, of which the central and decisive element, the Lázbérc reservoir, was made by man with a large scale modification of the landscape. The reservoir was built between 1967 and 1969 to ensure the water resources of the nearby industrial district of Ózd and Kazincbarcika.

The surface of the artificial lake is 78 hectares, its average depth is eight meters and lies between high peaks in one of the beautifully situated deep canyons of the Uppony mountain linked to the north side of the Bükk Mountains. The two-forked long and narrow lake follows the shape of the valley and is surrounded by a one hundred and twenty meter wide highly protected zone, what is more even the trees were cut down in a twenty meter zone directly next to the lake. Despite the strict regulations the area is freely accessible for visitors except for the strip of the shore ***[http://www.foek.hu/]***.

Fig. 4.2.2 View of the Lázbérc Reservoir and Landscape Protection Area [Original, 2005]
Fig. 4.2.3 Map of the Lázbérc Reservoir and Landscape Protection Area [Original, 2004]

On the Hungarian side the environmental protection law determines the issue of "ex lege" protected zones. The springs and sinkholes fall into this category in our study area. (According to the law, the springs that have yielded over 5 l/min are classified to fall into this category.) The number of these springs can only be guessed at, since most of them are seasonal springs and that makes it hard to evaluate their number exactly. The environmental inventory of the springs is in process at a moment. Altogether there are over 1000 environmental value pieces, and their water protection role is very significant, especially for the sinkholes. (In the beginning of this chapter I already talked about the sinkhole caves, the possibilities of karst water pollution, the cave cleaning program and its results.)

4.2.8.7. International protection

All the caves of both the Slovak Karst National Park and Aggtelek National Park and some parts of the national parks fall under international protection. Within the frame of international protection, the following points must be mentioned:

- Area of World Heritage, in cultural and environmental category, both countries together, based on the caves of the national parks of both countries
- Biosphere reserves in both national parks (Baradla Cave System and related wetlands)
- Ramsar sites in both national parks.

The caves of the Aggtelek Karst and Slovak Karst are part of the World Heritage since 1995 ***[Bolner-Takács and Székely, 1995; Székely and Takácsné, 1996]***. Let me highlight some aspects of the official introduction of the World Heritage Area – with some completion and refinement.

Ranging from the southern foothills of the Carpathian Mountains on the international border between Southern Slovakia and Northeastern Hungary. Lies within Borsod-Abaúj-Zemplén County in Hungary and Roznava District and Košice County District in Slovakia. The caves lie within Aggtelek National Park and Slovenský Kras Protected Landscape Area 48°25'-48°40'N, 20°15'-21°00'E.

The Aggtelek Karst was first declared a protected landscape area in 1978, and in 1985 became a national park by law. Slovak Karst was proclaimed a protected landscape area in 1973, which was reclassified as national park in 2002. (It became the 8th national park of Slovakia.)

Both sites have been individually accepted under UNESCO's Man and the Biosphere Programme ***[Bartus et al., 1982]***, Aggtelek National Park in 1979 and Protected Landscape Area Slovak Karst in 1977.

The caves systems of these protected areas were jointly inscribed on the World Heritage List in 1995. The terrestrial area that protects the caves comprises Aggtelek National Park and Slovak Karst National Park. However, the area of the World Heritage Property is considerably smaller as it only includes the caves themselves.

In both countries, in the Baradla-Domica cave system there are ramsar areas ***[Gunn, 2004]***.

4.3. Ways to satisfy the ecological water demand

The water demands (water supplies) can be grouped into ecological and economical water demand. (In my opinion the term „ecological" is only momentarily, due to technical reasons. Clearly ecological usage of water serves the best interest of the economy on the long run.)

Nowadays the most important regarding the usage of the karst water is to satisfy the economical water demands in the Bükk and its surroundings. The specifically ecological water demand is subservient, ***(Figure 4.3.1-4.3.4)*** at times and places the water „set aside" for the purposes of environment protection and landscape protection is not the optimal amount. The environment protection is trying to use the water of as many springs as possible for environmental purposes ***[Uray, 1994, 2002; Szablyár, 1996; Kosel et al., 1996; Lénárt, 1997c,***

2004b; Gasztonyi, 2002; Vojtilla, 2002; Havas et al., 2003; Jetel, 2004; Lénárt and Tometz, 2004].

Besides these positive issues let me mention another, rather sad issue as an example of the existing problems. This must be handled for water protection purposes as well ***(Figures 4.3.5-4.3.6)***. Many very similarly ruined pools and baths can be found in the study area. These are usually close to springs - or are themselves the spring – so their reconstruction or abolition is a must from the water protection point of view.

Fig. 4.3.1-4.3.2 The sinter cone of Egerszalók and the ecological water usage [Original, 2004]

Fig. 4.3.3-4.3.4 Spring engaged for ecological purpose, Kács [Original, 1998, 2000]

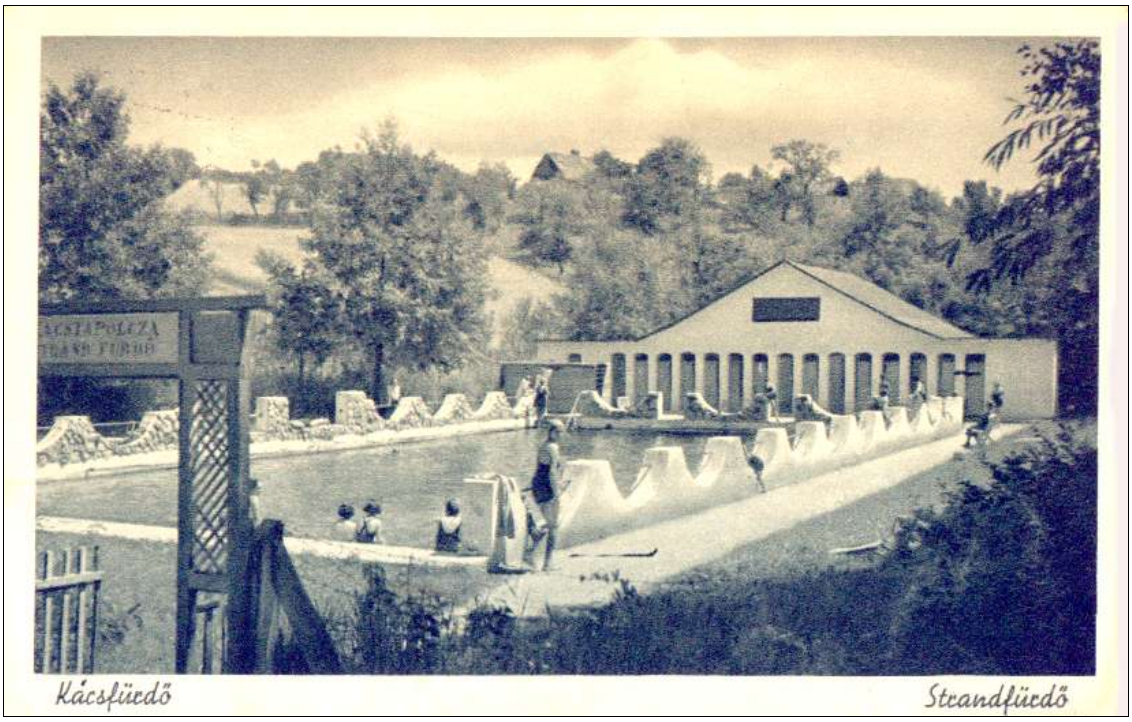


Fig. 4.3.5 Postcard of the Kács Bath in the 1930's

Fig. 4.3.6 Kács Bath on 2004. Aug. 14 [Original, 2004]

To decrease the ratio of ecological-economical water supplies is only possible if other kind of water (In case of Bükk and Aggtelek Karst, the bank-filtered water) is being used to meet the water demands, but it would have serious economical consequences. ***Figure 4.3.7*** shows this in theory ***[Lénárt et al., 1997]***.

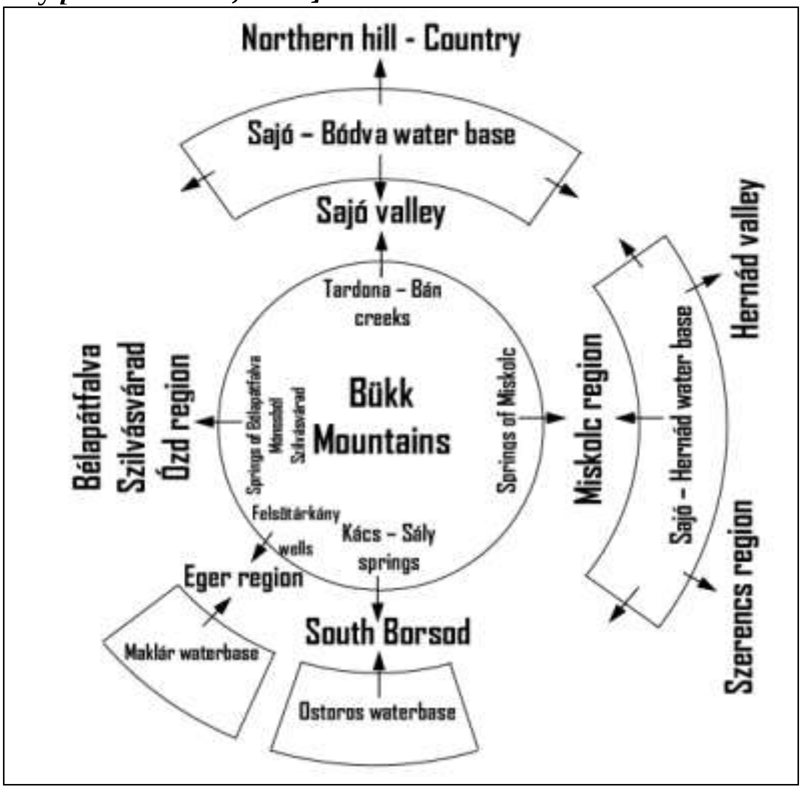


Fig. 4.3.7 The water distribution system in the Bükk Mountains area [Lénárt, 2004, based on Orbán, 1994]

4.4. Pollution vulnerability evaluation of the karst areas

Any karstic area is usually considered increasingly vulnerable for pollutions, therefore increasingly endangered. Only in the last years was accepted the theory that this vulnerability might have different degrees. First of all it concerns the usage of the area. It does matter if an area is being used for certain economic activities, even if with restrictions, or if an area is completely restricted. Let me mention a few of the works regarding the methods, examples and principles of determining the vulnerability of a given area ***[Sárváry, 1997; Németh, 2001; Mádlné et al., 2003; Havas et al., 2003; Malik and Švasta, 2004]***.

4.5. Further opportunities for karst water exploitation

I already mentioned that the economical and ecological water resources are being sharply separated nowadays. When someone talks about an increase in the water production, it is almost sure that the person means satisfying the newer and newer economical water demands.

In our study area the cold karst water exploitation is primary, but a new question comes up mainly in case of Bükk and its surroundings: the demand for exploiting more and more thermal karst water.

According to the previous chapters the cold karst water exploitation of the Bükk and its surroundings is not violating the EU 2000/60/EC Water Framework Directive, but the economic/ecological exploitation situation could be improved. In case of thermal water should greater amount of thermal karst water be exploited than it is being exploited now, even if it is only a few percent more, that would result in irreversible damage to the thermal karst system? (Further serious research and clearer legal order is necessary in this area.)

5. Ethics

In chapter „Methods of research" I already mentioned that out of the three E's (environment-economics-ethics) I can mainly deal with the environment, talk about the second one in less detail and only touch upon the third one. I wish to introduce a few thoughts in this chapter about ethics, because these expectations are not too matured, not too valid in our countries. But we must examine these questions in detail in the near future in order to find a way leading on. (Based on chapter Four and chapter Five, the situation is clear: the water resources management is becoming more and more complex, to resolve the situation the joint work of professionals from many different trades is necessary. The karst water management is not an exception, especially not in a situation when transboundary waters are concerned. Even the European Union expects us to find a solution good for both countries, since we are both members of this community.)

5.1. Strengthening the local approach in decision-making

It stands to reason that really well thought out professional decisions can be reached only if the participants have throughout local knowledge. Therefore any professional-political decision will only be effective and supported by the local communities if the decision is in the best interest of the local citizens.

At a moment the water usage-water system is partly centralized (large water producer companies), partly composed of small water companies only supplying a couple of settlements. Not easy to find a balance between these companies on a professional-economical level, but it must be attempted.

The water management as a profession is in a period of transition and the final results are still not clear. The decision-making authorities regarding water management had been centralized but without the necessary strengthening of the professional team on the job. The increased exploitation of the thermal water resources had become a government-political issue, without an accepted long-term water management plan. These decisions brought without the necessary professional opinions can have harmful effects in a long run. In the case of the Bükk, the karst water overexploitation will cause a decrease in the temperature, amount, pressure and water level in the wells. This will lead to disastrous situations regarding balneotherapy and bath-tourism, since the prices will increase so much that it might make it impossible to continue them.

In Northern Hungary – including the Bükk – presently the water production is becoming decentralized. In certain cases the service and the assets are separated, and it makes water management even more difficult. Doubtlessly, the local point of views getting into more and more focus – unless stranger companies buy the water companies - but in making the main decisions the valid professional opinions are not playing a very important role.

5.2. Public participation in decision-making

A good way to represent the best interests of the locals beside the municipal government is the professional, social groups and strata associations. (At a moment more than one „transboundary group" is known. The role of the European Union-style regions and smaller areas is becoming more and more important. Presently we don't take advantages of the possibilities of these structures yet, but along the borders – for example, in the cases of working out transboundary protected zones – this kind of activity should increase significantly.) There are many experts in this circle who can – and wants – to help their environment professionally. (It is a priceless value in the present's difficult economical society. But still in many cases a community with low economy might not be able to afford to pay for the work of an expert even when it is clear that the work of the expert is absolutely necessary.)

The professional-society's background cannot be dismissed even in case of such a large unit like the Bükk and its surroundings. It is not a coincidence that the centre of Bükk Area Sustainable Water Management Foundation is here, the local group of the Hungarian Hydrological Society is very strong here, the Ecological Institution for Sustainable Development is based in Miskolc city, the local speleologists are well-organized, and there are many environmentalist groups. The works of these groups will be even stronger in the future; it will be significant to spread the „spirit" of Water Framework Directive.

5.3. Introduction of the environmental values

Effective environment protection is only possible through the introduction of the elements of nature, information giving regarding nature and making participants value and respect nature and its elements. In this work the short-sighted view of "nature consists only of living creatures" must be put aside. We must accept that the elements of environment consisting of living and non-living entities, values of spectacle and cultural-history as well. The natural base for all these is the water, they all originate from water. (Since the study area mostly consists of dolomite and limestone, the noun "water" in this case should be completed with the adjacent "karstic".)

People are usually spectacle-oriented. If we show them a beautiful spring, a clean creek, a brook following its natural curves, a drop of filtrating water building a dripstone in a cave they probably will understand a lot about how nature works. And when they understood the essence of these processes they probably will help to protect the elements of nature, first of all the water.

In my opinion the most important parts for introducing the values of nature in our study area are the caves and the educational trails (mostly on the surface, but many of them underground, connected to caves) (Chapter 4.1). There are more than a dozen educational trails in the Bükk, quite a few in the Aggtelek Karst, and the situation is very similar in the Slovak Karst. (An exact number cannot be given because the number of these trails is constantly changing.) The educational trails are most interesting when written material can be given to complete the spectacles.

There are more and more ways to promote caves and educational trails, and it is practical to do so.

5.4. Education

The education is a very important tool to change the outlook of nature. I consider the following forms of education most important:

- In the official full-time education, starting from elementary school all the way to university, the studies regarding water should be increased on every level and passed on to the students.
- Decisions-makers – belonging to regional groups, municipality, water company, forest company, or official tender writers – should be partaking in continual education regarding the water and the problems that might be encountered about this issue, forming a group of "experts" on the issue.
- The strengthening of the education outside schools, within the frames of civil organizations, such as environmental and nature protection groups, caving associations, tourist groups, etc.

6. Thesis summary

6.5. Determination of the infiltration factor by using in-cave drip measurements

The most dominant soil cover on the study area is rendzina. It is several dm thick, its water conductivity equals to that of the mud – silty mud. It means an infiltration factor of 10^{-3} -10^{-5} m/s. Based on the in-cave drip measurements, I found the 140 m thick well-karsted limestone layer's infiltration factor (equivalent value) here is about 10^{-2}-10^{-3} m/s. The amount of the locally infiltrated water is being determined by the characteristics of the soil cover. ***(Chapter 3.3.1)***

6.6. The interpretation of the two- and three-phase infiltration in the epikarst

Following precipitation event, the three-phase infiltration process starts in the epikarst. The infiltrating water pushes the air in front of itself from the joints and therefore dissolves it. First we can detect an increase in yield from the end of the stalactites, then – as the water with high air content enters the space – the yield decreases. When only the water remains present – this is the two-phase infiltration – the drip yield gradually and greatly increases. This will last as long as there is gravitationally percolating water in the soil cover ***(Figure 3.3.11)***.

6.7. The connection between precipitation and karst water level

The karst water level reacts to the (Bükk Mountains – wide) precipitation from „bottom to top". The quickest increase in water level can be detected at the springs situated near the edge of the mountain. Next are the monitoring wells that are above impermeable layers, and finally the water level increases in the karstic areas that are situated in a distance from non-karstic areas ***(Figure 3.4.15)***. (This is one of the arguments that supports that the Bükk has a unified karst water system.)

6.8. The dynamics of decrease of karst water level

The continuous decrease in karst water level usually doesn't last longer than 3 months at a time. Due to this, it is very difficult to give long-term prognosis regarding the water level originating from precipitation. Starting on April 13, 2000, the karst water level in the Bükk had been decreasing continuously for more than 9 months. As a result, the water level decrease was over 21 meters. A sixth-degree diagram had been fitted to the daily measurement results. The correlation is very high (R^2 = 0,9985). Prognosis given monthly to the waterworks for 30 and for 60 days in expected water levels and water amounts can be given based on this algorithm ***(Figure 3.4.27)***. The formula used is the following:

$$\mathbf{y = 0{,}000000000003x^6 - 0{,}000000643626x^5 + 0{,}059173040051x^4 - 2901{,}435073242290x^3 + 80024693{,}7785473x^2 - 1177154795759{,}77x + 7214920549840510}$$

$$\underline{\mathbf{R^2 = 0{,}9985}}$$

6.9. The connection between the water levels recorded at different monitoring sites

The tightest the connection (r^2 = 0,87) between the water levels measured at different sites of the monitoring network, when the difference in pressure is great (approx. 30 bar = 3 MPa). The loosest is the connection (r^2 = 0,74) in the case of smaller pressure difference (approx. 16 bar = 1,6 MPa). (This happens regardless if there are impermeable or permeable layers between the monitoring wells.) This is another argument that supports that the Bükk has a unified karst water system ***(Table 3.4.II)***.

6.10. The lunisolar effect at the individual monitoring sites

The effect of the Moon on the karst water changes was recorded before in many places, in many different method of survey. It is clearly noticeable in the Bükk as well, in the strongly increasing, in the strongly decreasing and even in the less changeable periods. The greatest is the change in the karst water level monitoring wells that are situated at the base of the mountain, lower in the karst water monitoring wells of the plateau, but still a few centimeters. The lowest is in the springs that have large free cubic content and are captived for water production, situated at the edge of the mountain. In the monitoring boreholes the water level increases at Moon-rise and Moon-set, and decreases when the Moon is at the highest point of its orbit ***(Figures 3.4.58-3.4.61)***.

6.11. Determining the amount of effective precipitation

The rainfall becomes „effective precipitation" only with a few conditions (will cause significant karst water level and spring yield increase).

- at least 50 mm precipitation must fall, in form of rain, within one day time
- if the 50 mm precipitation falls not within one day, but within a few days time, the maximum pause (precipitation-free day) between precipitation days can be one day only

In the Bükk 1 mm „effective precipitation" causes 5.18 cm karst water level increase on the average. The most significant specific karst water level increase is in March (8 cm water level/mm precipitation) and in November (6 cm water level/mm precipitation). The least effective the precipitation is derived in July ***(Figure 3.4.65)***.

6.12. Categorization of karst waters by temperature

The rating of waters by their temperature can be done by many different methods. Usually only the waters warmer than 30°C are categorized as thermal waters in Hungary. The reason for this is that the heat of the thermal water can be used up above this temperature. This rigid and technical limit is not justified from the hydrogeological point of view. The mixing of cold and warm waters is an important genetic feature, so I propose a sub-thermal range (10-25°C) between the cold and warm category. The most prevalent method in hydrogeology for karst water under the temperature of 25 degree Celsius can be developed further by the following:

	Bükk	**Aggtelek Karst, Slovak Karst**
cold water	< 10 °C	< 9 °C
cold-tepid water	10-16 °C	9-15 °C
warm-tepid water	16-25°C	15-25 °C
warm water	25-37°C	25-37°C
hot water	> 37 °C	> 37 °C

To determine the categories we should take the minimum values of the temperature of the exploited water. (The border between the cold and cold-tepid waters corresponds to the local annual average air temperature. The border between the cold-tepid and warm-tepid is the average air temperature of the hydrological summer season.)

6.13. The dangers of increased exploitation of the karst waters of the Bükk

The cold karst water on pressure level of the Bükk at 523-544 m a.B.s.l. controls the outflow of the cold-tepid and warm-tepid springs at 120-205 m a.B.s.l., and drainage depths of the warm waters and hot waters at -150 – -2.200 m a.B.s.l. The Bükk forms a connected cold-warm karst water system, with separable partial aquifers at certain level of the evaluations. The karst water level exploitation of the Bükk has reached such level nowadays that any additional exploitation would endanger the entire system (temperature drops, depression increase, pressure drops) ***(Figures 3.4.72-3.4.78)***.

6.14. The delineation of the thermal karstic water bodies on the study area

The delineation of the thermal karst on the study area, based on the EU Water Framework Directive, only took place on the Hungarian side of the border, due to the water temperature (around 20 °C) on the Slovak side. But is we accept the categories listed in Chapter 6.8, the border of sub-thermal karst waters can be extruded further North, based on hydrogeological reasons.

There are signs of thermal water on the study area both on the surface (Tapolca-Teplica names, tepid and warm springs), both in the caves (Miskolctapolca Várhegy caves, Esztramos, Teplice-cave, etc.). Due to the EU Water Framework Directive, I think the delineation of the thermal karstic water bodies on all three areas is reasonable ***(Figure 3.4.66)***.

6.15. The content of Radon in the spring water depending on the rock

The amount of the Radon in the waters moving through the rock depends on kind of rocks the water moves through. The average amount of radon concentration is between 0,5-12 kBq/m^3 at certain sites of the Bükk. The extent of the radon concentration is mostly depends on the kind of rock it moves through and the kind of rock it emerges from. In a measurement session taking many years in the Bükk it was proved that the highest average Radon concentration of the water was in the water emerging from detrital shale (6,76 kBq/m^3), next was water emerging from the porphyrite (4,74 kBq/m^3), then the dolomites (3,05 kBq/m^3), limestone (1,63 kBq/m^3), and finally the water emerging from sinter (travertino) (1,45 kBq/m^3) ***(Figure 3.5.6)***.

6.16. The pollution of karst water through caves

The pollution of karst water through caves can be dangerous in different degree. The types of caves that potentially endanger the karst water are the following:

- the spring caves that are in water company spring areas,
- caves that have corridors or shafts which are close to the karst water level, or are at karst water level,
- the most significant active sinkhole and sinkhole caves,
- the open shaft caves that are located close to inhabited places,
- the caves which are located close to roads,
- the caves which are visited heavily and frequently,
- the deep shaft-caves or shafts, regardless of their location

94 out of the evaluated 761 caves of the Bükk had been classified by my field and research work as potential pollution source.

7. Literature

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